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REPORTS, PAPERS, DISCUSSIONS, AND MEMOIRS

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CONTENTS

Papers: PAGE

Specifications for Transit Traversing and Stadia Leveling.
BY W. H. RAYNER, ASSOC. M. AM. SOC. C. E. ... 2639

Comments on the Design of Sludge Digestion Tanks.
BY RICHARD H. GOULD, M. AM. SOC. C. E. ... 2655

Relation of the Landscape Architect to the Allied Professions Engaged in City Planning.
BY ARTHUR A. SHURTLEFF, ESQ. ... 2667

Engineering Applied to National Parks.
BY STEPHEN T. MATHER, ESQ. ... 2673

Discussions:

Flood Control with Special Reference to the Mississippi River.
BY MESSRS. W. E. ELAM, R. W. DAVENPORT, and E. W. LANE ... 2685

The Virginian Railway Electrification.
BY GEORGE GIBBS, M. AM. SOC. C. E. ... 2701

Hydrostatic Uplift in Pervious Soils.
BY MESSRS. J. ALBERT HOLMES and E. W. LANE ... 2707

Modernizing the Suburban Transit of the Metropolitan District.
BY HAROLD M. LEWIS, M. AM. SOC. C. E. ... 2711

A Proposed Formula for Columns.
BY MESSRS. HENRY S. PRICHARD, E. H. SALMON, C. N. ROSS, K. L. DE BLOIS, and EDWARD GODFREY ... 2721

The Stiffness of Suspension Bridges.
BY MESSRS. E. STEUERMANN and GEORGE C. PRIESTER ... 2737

The Relation Between Earthquakes and Engineering Structures.
BY MESSRS. WALTER E. SPEAR, M. M. O'SHAUGHNESSY, and BAILEY WILLIS. 2749

The Practical Utility of Highway Transport Surveys.
BY MESSRS. R. H. SIMPSON, W. A. VAN DUZER and C. R. THOMAS, JR. ... 2755

Memoirs:

HENRY SEWALL ADAMS, M. AM. SOC. C. E. ... 2765
GEORGE HERBERT BOYNTON, M. AM. SOC. C. E. ... 2767
WILLIAM SANBORN DAWLEY, M. AM. SOC. C. E. ... 2770
FRED ATWOOD JONES, M. AM. SOC. C. E. ... 2773
BATTLE HARGROVE KLYCE, M. AM. SOC. C. E. ... 2774
CHARLES KENNETH CURRY, ASSOC. M. AM. SOC. C. E. ... 2776
LUCERN S. STEWART, AFFILIATE, AM. SOC. C. E. ... 2777
WILLIAM BACON WELLS, JUN. AM. SOC. C. E. ... 2779

For Index to all Papers, the discussion of which is current in *Proceedings*, see the second page of the cover.

AMERICAN SOCIETY OF CIVIL ENGINEERS
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PAPERS AND DISCUSSIONS

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SPECIFICATIONS FOR TRANSIT TRAVERSING AND STADIA LEVELING

By W. H. Rayner,* Assoc. M. Am. Soc. C. E.

Synopsis

This paper has for its purpose a consideration of the effect of the errors in combination which attend the work of transit traversing and stadia leveling. It indicates a method whereby specifications for each operation in the field work may be prepared, so that the survey as a whole may be most economically and expeditiously executed.

The theory of errors has been adequately developed elsewhere, but for the most part, it has been applied to measures of precision, such as the probable error, and others, and to the adjustment of observations by the method of least squares. Authors of textbooks treat the various sources of error separately, but the total effect of the errors in combination in the surveying processes, appears to have received but little consideration. This is especially true as regards surveys of ordinary or low precision.

Many surveys are so simple in plan and are of such small scope that any detailed analysis of the methods would be absurd, but it has been the writer's observation that engineers who deal with surveys only occasionally, are apt to use about the same procedure and precision for one and all alike, with the result that on work of any magnitude or importance much time is wasted, either in unnecessarily refined measurements or in repeating the measurements to achieve satisfactory results.

It may be added that this paper is intended to indicate a method only, and is not a complete treatment of the subject. Many sources of error that are not mentioned will be found important under certain field conditions; but the method indicated herein should enable the engineer to specify intelligently—for any survey and under any conditions—the care which should be used for each part of the field work.

Note.—Written discussion on this paper will be closed in March, 1929.

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Definitions

In the usual treatment of "systematic errors" it is assumed that, in some cases, their effect can be eliminated either by corrections applied to the measured quantity, or by systematic field methods. Thus, it is stated, the effect of the incorrect length of tape can be corrected by a computation, or the effect of non-parallelism between the axis of the level tube and the line of sight in an engineer's level may be eliminated by taking foresights and backsights of equal length. In this paper, however, a fundamental conception is that an error always is a quantity of which both the magnitude and the sign are unknown. Accordingly, in so far as the conditions mentioned do not affect final results, they are not considered as errors. In accordance with this conception, the following definitions are given.

A Systematic Error.—An error which always has the same (unknown) sign, and, therefore, is cumulative in its effect—but the magnitude of which cannot be calculated—is a systematic error. Its effect cannot be removed by systematic field methods.

Accidental Errors.—Such errors have the following characteristics (assuming that a large number of observations are taken): (*a*) Plus and minus errors are equally numerous; (*b*) small errors are more numerous than large ones; and (*c*) very large errors do not occur.

A Cumulate.—That part of the effect of a source of error which can always be eliminated either by a computation, or by a systematic field method, is termed a cumulate.

Mistakes.—Differences from true values, arising from confusion in the mind of the observer, are mistakes. They are detected by checking the work and are eliminated by applying corrections. It need not be added that the subject of mistakes has no place in a discussion of errors.

The Probable Error.—This is an error of such magnitude that in a series of like measurements, the number of errors larger, equals the number of errors smaller, than the probable error. In other words, in a series of like measurements, the probable error has such a value that the chances are even that the error in any single measurement, taken at random, is smaller (or larger) than the probable error.

These definitions are made clearer by the following examples.

Example 1.—Let it be supposed that a steel tape is to be used in a careful survey. It is sent to the U. S. Bureau of Standards, Washington, D. C., where its length is determined to be $100.021 \pm x$ ft. In using the tape its length is assumed to be 100.000 ft. Hence, the quantity, 0.021, is the cumulate and the quantity, $\pm x$, is the systematic error. In the process of chaining, the small errors made in marking the ends of the tape are accidental errors; and a mistake would be made if a fractional distance of 59.13 ft. was misread as 61.13 ft.

Example 2.—A level party is required to carry a line of levels across a river. The levelman reads a rod held on a bench-mark on the near bank of the river (B. $M._1$), as $4.37 \pm x$ ft., and on the far bank (B. $M._2$) as $8.31 \pm y$ ft., from which the difference in elevation is determined as 3.94 ft. He calculates

the effect of curvature and refraction to be 0.04 ft. This is subtracted from the reading on B. M.$_2$ and the corrected difference in elevation is determined as 3.90 ft. In this case the quantity, 0.04 ft., is a cumulate; $\pm x$ and $\pm y$ are differences from true values affected by both kinds of errors: (1) The accidental errors arising from such causes as leveling the instrument, sighting, holding the rod, etc.; and (2) the systematic error due to the imperfect adjustment of the instrument.

Theory of Errors and the Inter-Relation of Errors

No attempt is made in this paper to derive the fundamental formulas.

Compensation.—This principle states that in a series of observations affected by an accidental error the total probable error is given by the product of the error in a single observation times the square root of the number of observations. Thus,

$$E_t = E_s \sqrt{n} \quad \ldots\ldots(1)$$

in which, E_t is the total probable error; E_s is the probable error of a single observation; and n is the number of observations in the series.

The Summation of Errors.—This principle states that if the total probable error of a measurement is the result of several errors acting independently, the value of the total probable error is given by the square root of the sum of the squares of the separate probable errors arising from the several sources. Thus,

$$E_t = \sqrt{E_1^2 + E_2^2 + E_3^2 + \ldots\ldots E_n^2} \quad \ldots\ldots(2)$$

in which, E_t is the total probable error and E_1, E_2, etc., are the separate probable errors affecting the measurement independently.

The Product of Errors.—If a measured quantity, x, is the result of two independently measured quantities, A_1, A_2, such that $x = A_1 \times A_2$, then,

$$e_x = \sqrt{A_2^2 e_1^2 + A_1^2 e_2^2} \quad \ldots\ldots(3)$$

in which, e_x is the error in the quantity, x, and e_1, e_2, represent the errors in the quantities, A_1 and A_2, respectively.

The more general form of this relationship is expressed in terms of the partial derivatives. Thus,

$$d_x = \sqrt{\left[e_1 \frac{\delta x}{\delta A_1}\right]^2 + \left[e_2 \frac{\delta x}{\delta A_2}\right]^2 + \ldots\ldots + \left[e_m \frac{\delta x}{\delta A_n}\right]^2} \quad \ldots\ldots(4)$$

Example 3.—The area of a rectangular city lot has been determined by the measurements: The length, $A_1 = 122.3 \pm 0.04$ ft., and the width, $A_2 = 48.3 \pm 0.03$ ft. What is the probable error in the area?

By Equation (3), since $x = A_1 A_2$,

$$e_x = \sqrt{48.3^2 \times 0.04^2 + 122.3^2 \times 0.03^2}$$
$$= \pm 4.1 \text{ sq. ft.}$$

Example 4.—The height of a transit station has been computed from the measurement of a slope distance, $L = 837.3 \pm 0.2$ ft., and of a vertical angle, $\alpha = 3° 20' \pm 30''$. What is the probable error in the calculated elevation of Station A?

$$H = L \sin \alpha$$

and, therefore, by Equation (4),

$$e_H = \sqrt{e_L{}^2 \sin^2 \alpha + e_a{}^2 \cos^2 \alpha \, L^2}$$
$$= \sqrt{0.2^2 \times 0.058^2 + 837^2 \times 0.00015^2 \times 0.998^2}$$
$$E_H = \pm 0.12 \text{ ft.}$$

Sources of Error in Chaining

The principal sources of error in chaining may be described briefly as follows:

(*a*) *Length of Tape, E_l.*—This source of error arises from the fact that a comparison made between a steel tape and standard length, is not exact. A certificate given by the U. S. Bureau of Standards for a steel tape, is as follows:

"Bureau of Standards Certificate

"This certifies that 100-Foot Steel Tape No. 2432 has been compared with the standards of the United States and, for the intervals indicated, has the following corrections at 62° Fahrenheit when supported horizontally throughout its entire length under a Tension of 12 pounds avoirdupois:

Interval	*Correction*	*Probable Error*
(0 to 100 ft.)	— 0.002 foot	± 0.0003
Tension: 20 pounds (0 to 100 ft.)	+ 0.006 foot	"
Tension: 30 pounds (0 to 100 ft.)	+ 0.015 foot	"

"Note: The foregoing comparisons were made at the 0- and 100-foot lines on the brass sleeves.

"*A* + Correction means that the tape is too long, *i. e.*, longer than the nominal length of the interval; *a* — Correction that it is shorter by the amount indicated.

"The comparisons of this tape with the United States Bench Standard were made at a temperature of 83° Fahrenheit and in reducing to 62° Fahrenheit, the coefficient of expansion of the tape is assumed to be 0.0000062 per degree Fahrenheit."

While in use, a 100-ft. steel tape is assumed to be exactly 100 ft. long; but reference to the certificate shows that for this tape its length at 62° Fahr. and under a tension of 12 lb., is 99.998 ft. ± 0.0003 ft. Hence, the cumulate is 0.002 ft. and the systematic error is ± 0.0003 ft.

(*b*) *Temperature, E_t.*—It will be noted that the U. S. Bureau of Standards certificate states the length of the tape at a temperature of 62° Fahr. and gives the value of the coefficient of expansion as 0.0000062 per degree Fahr. Hence, if the tape in the field has another temperature its length will be changed by an appreciable amount.

If the field temperature is not determined, its effect becomes a systematic error. If the value of the field temperature is determined, the change in length becomes a cumulate and may be eliminated by the proper computations.

However, because the temperature cannot be measured exactly, there will result a corresponding small systematic error in the length of the tape. If it is assumed that the temperature remains approximately constant for a given

measurement, the errors resulting from temperature changes are systematic in kind.

(*c*) *Grade, E_g.*—Since the horizontal distances only are desired in taping, small errors will always be caused by the slope of the ground. This will be true whether the tape is stretched level or stretched on the ground because in the first case there will be a small deviation from a truly horizontal position and in the latter case there will be a small error in determining the inclination of the slope.

If the tape is stretched level, the resultant error will be systematic in kind because whether the tape is inclined upward or downward the resultant error will have the same sign. If the tape is stretched on the ground and if no correction is applied to the measurements, the errors (as in the case when the tape is not held level) will be systematic in kind. If, however, the inclination of the slope is determined, a cumulate is produced, and the corresponding correction can be applied. However, because of the errors in estimating the slope, small resultant errors will remain in the tape measurements, and because some estimated values of slope will be too great and some too small, the resultant errors will be accidental in kind.

Moreover, it will be noticed in Table 1 that a variation of, say, 1 ft., has different values for different slopes. For example, the variation between a 2% and a 3% slope is accompanied by a variation of 0.03 ft. in the error or cumulate; but the variation between a 6% and a 7% slope is accompanied by a variation of 0.07 ft. in the error or cumulate. This condition must be carefully observed in calculating the probable error due to slope of the ground.

(*d*) *Alignment, E_o.*—The effects of errors of alignment are exactly similar to those of grade, except that they can be minimized much more easily.

(*e*) *Sag, E_s.*—Whenever it is held off the ground a tape sags. For known conditions of pull, weight, and size of tape, cumulates may be computed and the corresponding corrections applied. Because of errors in determining the values of pull, weight, and size, small errors result. Since the variation in pull is the largest factor in causing the resultant error and because the amount of the pull will vary both above and below the estimated value, this resultant error will be accidental in kind.

If no correction for the effect of sag is applied, a systematic error results. Table 1 gives the values of the cumulates or errors for various conditions.

(*f*) *Marking Tape Lengths, E_m.*—The position of the end of the tape is usually marked with a stake, a pin, or kiel. Since this position can never be indicated exactly, and the distance thus indicated is as likely to be too great as too small, there result accidental errors the magnitude of which depend on the care used in marking.

(*g*) *Pull, E_p.*—A tape is elastic. It therefore has its correct length only under a given standard pull. For any other pull, the tape will be too long or too short and resultant accidental errors are caused. This effect of pull should not be confused with its effect on sag as considered under Article (*e*).

TABLE 1.—CUMULATES OR ERRORS IN TAPE MEASUREMENTS. 100-FOOT TAPE.

E_t, THERMAL EXPANSION.		E_p, STRETCH.		E_g, E_o GRADE, OR ALIGNMENT.		Weight of tape, in pounds.	E_s, SAG.				
							Pull, in Pounds.				
Temperature change, in degrees.	Cumulate or error, in feet per 100 ft.	Pull, in pounds.	Cumulate or error, in feet per 100 ft.	Percentage of slope, or deviation from line.	Cumulate or error, in feet per 100 ft.		Cumulate or error, in feet per 100 ft.				
							8.	10.	12.	15.	20.
7	0.005	7	0.005	1	0.005	1	0.065	0.041	0.029	0.019	0.012
15	0.01	15	0.01	2	0.02	1¼	0.092	0.058	0.041	0.025	0.014
22	0.015	22	0.015	3	0.05	1½	0.146	0.092	0.062	0.041	0.022
30	0.02	30	0.02	4	0.08	1¾	0.211	0.135	0.092	0.059	0.034
37	0.025	...	.....	5	0.12	2	0.260	0.167	0.110	0.073	0.041
45	0.03	...	.....	6	0.18	...	.....	.....	.....	.....	.....
52	0.035	...	.....	7	0.25	...	.....	.....	.....	.....	.....
60	0.04	...	.....	8	0.32	...	.....	.....	.....	.....	.....
67	0.045	...	.....	9	0.41	...	.....	.....	.....	.....	.....
75	0.05	...	.....	10	0.51	...	.....	.....	.....	.....	.....

(*h*) *Wind, E_w.*—If a tape is stretched unsupported and a strong wind is blowing, the center of the tape will be carried to one side of the line joining the two ends of the tape. This condition causes an effect similar to, but usually much less than, that of sag.

Sources of Error in Horizontal Angles

The principal sources of error in the measurement of horizontal angles are: (*a*) Centering the instrument over a point; (*b*) sighting a point; (*c*) reading the verniers; and (*d*) inaccurate adjustment of the instrument. These errors are mainly accidental in kind. A notable exception is the effect of non-perpendicularity between the line of sight and the horizontal axis of the instrument if, in traversing, the backsight is always taken with the telescope inverted, and the foresight is taken with the telescope normal, or *vice versa*. If this procedure is followed, a systematic error results. It can be largely eliminated and rendered an accidental error if at alternate stations the backsight is taken at the first station with the telescope inverted, and at the next station with the telescope normal. In careful work all the errors of non-adjustment are greatly minimized and rendered accidental in kind by double sighting, the telescope being reversed between sights.

Effects of Systematic Errors in Traversing

Distances.—The effect of a systematic error in the length of the sides of a traverse is apparent in Fig. 1, in which, *A B C D E A* represents the true figure of a given traverse. For an assumed error in the length of the tape it is supposed that the true distance, *AB*, is measured as *AB′*, the error being *BB′*. Also, the true distance, *BC*, is measured as *B′ C′* and the total error at *C* is represented by the distance, *CC′*. The erroneous traverse, *AB′ C′ D′ E′ A*, is, therefore, similar in form to, and the sides are parallel with, those of the true figure. The total displacement of any point, as *C*, is given by the distance, *CC′*. This line is coincident in direction with, and proportional in length to, the line, *CA*, which may be called the radial line to the point of beginning, *A*. Likewise, the errors, *DD′* and *EE′*, are coincident in direction with, and proportional in length to, the radials, *DA* and *EA*, respectively. Since the error, *EE′*, is thus coincident with and proportional to the line, *EA*, evidently the error of closure at *A* is zero, which condition is plainly necessary if a systematic error is present throughout the traverse.

Angles.—The effects of the errors in the measurement of angles are accidental in kind, or they may be easily so rendered. Hence, the effect of systematic errors in angles will be disregarded.

Effects of Accidental Errors in Traversing

Distances.—The total linear error resulting from the accidental errors of measurement of any given side of a traverse, is independent of similar errors in the other sides of the traverse. Accordingly, the total combined effect may be considered to be a function of the length of the traverse only; and since accidental errors are compensative in their effect, the total probable error

resulting from the accidental errors of chaining will be given by the product, $E_L = e\sqrt{n}$, in which, E_L is the total probable error; e, the probable error of a single tape length; and n, the number of tape lengths in the traverse.

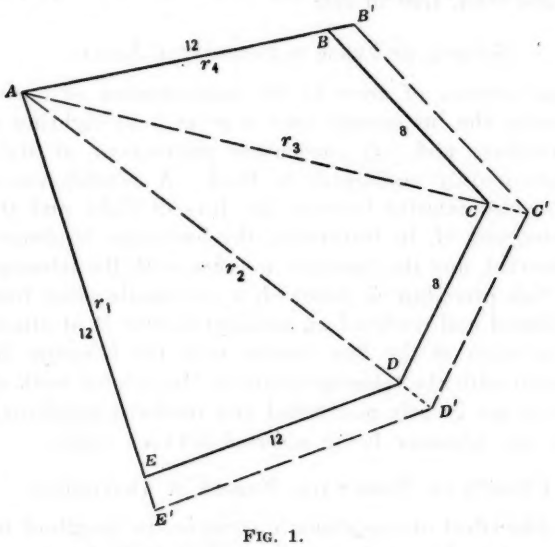

FIG. 1.

Angles.—Since the direction of each side of a traverse is determined by measuring the angle between it and the preceding side, it follows that an error made in measuring any given angle, affects all succeeding sides. This condition may be analyzed by reference to Fig. 1. An angular error at E will cause a linear error at A, the magnitude of which is given by the relation that, $e_1 = e_a \times EA$, in which, e_1 is the linear error at A; e_a, the angular error at E, expressed in radians; and EA, the length of the side, which may be expressed as r_1. Since 1′ of arc is very nearly 0.0003, in radians, then, if angles are read so that there is a possible error of 1′ in each one, $e_1 = 0.0003 \times r_1$.

Likewise, if the angular error at the station, D, is considered, the angle at E is now assumed to be without error, and an error in the direction of DE will displace the point, A, by an amount equal to the rotation of A about D through the angular error, e_a, at D. Hence, the linear error at A, due to angles only, will be given by the relation, $e_2 = e_a \times 0.0003\, r_2$, and, similarly, for the other stations, C and B. According to Equation (2) the total linear error at A will be,

$$E_A = \sqrt{e_a^2 \times 0.0003^2 (r_1^2 + r_2^2 + \text{etc.})}$$

$$= 0.0003\, e_a \sqrt{r_1^2 + r_2^2 + \ldots + r_n^2} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

SYSTEMATIC ERRORS IN AN OPEN TRAVERSE

Distances.—The total effect of the systematic errors in distances in the case of an open traverse has been indicated in describing the effect of these errors

in a closed traverse. Thus, in Fig. 1, it has been shown that the total error at any point, as D, for example, is proportional to the radial length, DA. Accordingly, in Fig. 2, let the points, A, B, C, D, and E, represent the transit stations of an open traverse, and let the lengths of the sides, in 100-ft. stations, be shown by the numbers thereon. Thus, $AB = 600$ ft., etc. Hence, in this traverse, the total systematic error in distance will be proportional to the length, $EA = 3\,300$ ft.

Angles.—The systematic errors in the measurement of angles will be disregarded in this paper.

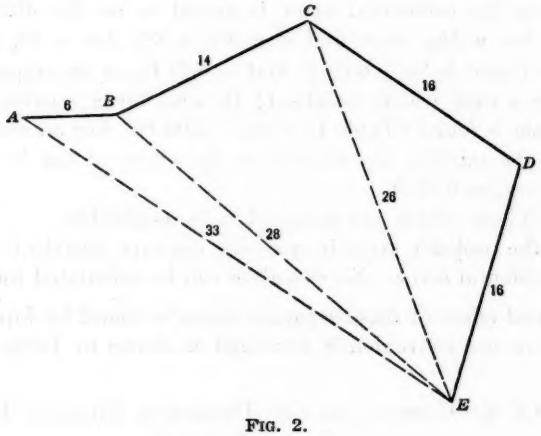

FIG. 2.

ACCIDENTAL ERRORS IN AN OPEN TRAVERSE

The total effect of the accidental errors both in distances and in angles will be of a similar nature, and the probable errors are calculated in the same manner, as those for the closed traverse.

APPLICATIONS OF THE ANALYSIS TO A CLOSED TRAVERSE

Example 5 illustrates the application of this method of analysis to a closed traverse.

Example 5.—In Fig. 2, let the lengths of the sides be: $AB = 12$; $BC = 8$; $CD = 8$; $DE = 12$; and $EA = 12$ stations, respectively. The traverse was run under the following conditions: The tape was 100.03 ± 0.01 ft. at 62° Fahr. when supported throughout under a tension of 12 lb.; the estimated average temperature of the tape was 90° Fahr.; the weight of the tape was 1½ lb.; the average ground slope was 5%; the country was partly open and partly wooded so that for one-half the distance, the tape was held horizontal (unsupported) and, for the other half, it was held on the sloping ground; the average error in marking the tape lengths was ± 0.05 ft.; and the average error in measuring the angles was 01′. What is the calculated total probable error of closure?

Errors in Chaining.—The magnitude of the cumulates and the probable errors may be calculated as follows:

(E_l).—Assuming the tape to be compared with a standard tape, the length is found to be 100.03 ± 0.01 ft. at 62° Fahr. Hence, the cumulate is $+ 0.03$ ft., and the systematic error is ± 0.01 ft.

(E_t).—It is assumed that the field temperature is estimated to be 90° Fahr. and that the probable error in this estimation is 15° Fahr. Hence, the cumulate (Table 1) is $+ 0.02$ ft. and the systematic error is ± 0.01 ft.

(E_g).—If the average slope is 5%, and if the tape is held on the ground one-half the distance, then the cumulate (Table 1), is $- 0.12$ ft. per tape length. Also, if it is assumed that the probable error in estimating the slope is $\pm$ 1%, then the accidental error is found to be the difference between the cumulate for a 5% slope and that for a 6% (or a 4%) slope. These differences are found to be $+ 0.06$ ft. and $- 0.04$ ft., or an average of ± 0.05 ft.

(E_s).—For a tape which weighs 1½ lb. and for a tension of 12 lb., the cumulate for sag is found (Table 1) to be $- 0.06$ ft. For an assumed variation of ± 3 lb. in the tension, the change in the effect of sag is $- 0.03$ ft. and $+ 0.02$ ft., or, say, ± 0.03 ft.

(E_p, E_o).—These effects are assumed to be negligible.

(E_m).—If the probable error in marking the tape lengths is $\pm$ 0.1 ft., this effect is an accidental error. No cumulate can be calculated for this source.

The combined effect of these separate errors is found by Equation (2), and the computations are conveniently arranged as shown in Table 2.

TABLE 2.—COMPUTATIONS TO DETERMINE CHAINING ERRORS IN A CLOSED TRAVERSE.

Source.	Cumulate.	Error.	Kind.	Amount, q.	q^2.
E_l	$0.03 \times 52 = + 1.6$	± 0.01	Systematic	0	.....
E_t	$0.02 \times 52 = + 1.0$	± 0.01	Systematic	0	.....
E_g	$0.12 \times 0.25 = - 6.2$	± 0.06	Accidental	$0.06 \sqrt{25} = \pm 0.3$	0.09
E_s	$0.06 \times 0.25 = - 30$	± 0.03	Accidental	$0.03 \sqrt{25} = \pm 0.15$	0.03
E_p	Neglect	.....	.....	.....	.....
E_o	Neglect	.....	.....	.....	.....
E_m	0	± 0.1	Accidental	$0.1 \sqrt{52} = \pm 0.7$	0.49
Σq^2	.....	.....	.....	.....	0.61

Total correction = $- 6.6$ ft.; total $E = \sqrt{0.61} = \pm 0.8$ ft.

Errors in Angles.—According to Equation (5), the total probable linear error of closure resulting from the accidental errors of measuring the angles is given by the relation:

$$E_A = 1 \times 0.0003 \sqrt{1\,200^2 + 2\,000^2 + 2\,000^2 + 1\,200^2} = \pm 1.0 \text{ ft.}$$

Total Probable Error of Closure.—Combining the probable errors for distance and angles, the total probable error resulting from both sources is,

$$E_T = \sqrt{E_L^2 + E_A^2} = \sqrt{1.0^2 + 0.8^2} = \pm 1.3 \text{ ft.}$$

This error of closure (about 1 in 4 000) may seem surprisingly small for the field conditions named. It indicates three important facts: First, that systematic errors in distances and in angles (provided they are present throughout the work) do not affect the error of closure; second, that the total errors of traversing can be easily and largely reduced if the cumulates are removed by simple calculations or by systematic field methods; and, third, that the computations are based on the assumption that the errors are accidental in kind. If any sources of error operate as systematic errors through a part and not all of the work, then the error of closure will be seriously affected thereby.

Application of Analysis to an Open Traverse

Errors in Chaining.—Let Fig. 2 represent an open traverse for which the same field conditions apply as those assumed for the closed traverse of the previous case.

It has been shown that the systematic errors in chaining from one point to another are proportional to the length of the line connecting these points.

The cumulates will be the same as those calculated for the closed traverse and the total probable error in chaining is calculated as shown in Table 3.

TABLE 3.—Computations to Determine Chaining Errors in Open Traverse.

Source.	Kind.	Amount, q.	q^2.
E_l	Systematic	$0.01 \times 33 = \pm 0.33$	0.11
E_t	Systematic	$0.01 \times 33 = \pm 0.33$	0.11
E_g	Accidental	$0.06 \times \sqrt{25} = \pm 0.30$	0.09
E_s	Accidental	$0.03 \times \sqrt{25} = \pm 0.15$	0.03
E_p		Neglect	....
E_o		Neglect	....
E_m	Accidental	$0.1 \times \sqrt{52} = \pm 0.7$	0.49
$\Sigma_q{}^2 =$			0.84

Total $E_L = \pm 0.9$ ft.

Errors in Angles.—The final error resulting from accidental errors in measuring the angles is calculated by Equation (2) as follows:

$$E_A = 1 \times 0.0003 \sqrt{2\,800^2 + 2\,600^2 + 1\,600^2} = \pm 1.2 \text{ ft.}$$

Errors in Chaining and in Angles Combined.—The combined effect of the errors in chaining and in angles may be represented by E_T and, therefore,

$$E_T = \sqrt{E_L{}^2 + E_A{}^2} = \sqrt{0.9^2 + 1.2^2} = \pm 1.5 \text{ ft.}$$

It may be noted that this traverse has the same length as that of the closed traverse, and the difference in magnitude between the errors of closure of ± 1.3 ft. for the closed, and ± 1.5 ft. for the open, traverse is caused entirely by systematic errors, operative in both cases. These were eliminated

in the closed traverse, but could not be eliminated in the open traverse. This condition calls attention to the necessity of giving careful attention to sources of systematic errors for traverses which do not close, if the errors are not to exceed prescribed limits.

Preparing Specifications

General Procedure.—In the preceding pages a method has been indicated whereby the total probable error of displacement of the terminal point of a traverse can be calculated if the field conditions are known. A principal purpose of this paper, however, is to indicate the reverse procedure; that is, for a known permissible error of displacement of the terminal point of a traverse, to write specifications for the field work such as will yield the desired results. Assuming that the permissible total error of displacement and the field conditions are known, the successive steps in the procedure are, as follows:

(*a*) Assign the total permissible error to the two general sources of error, namely, those of angles and distance, respectively.

(*b*) Assign values to the separate sources of error in the chaining such that their combined effect will not exceed the amount assigned to distance under Step (*a*).

(*c*) Calculate the permissible angular error for each transit station such that the combined effect will not exceed the amount assigned to angles under Step (*a*).

(*d*) Write the specifications to govern the field work in accordance with the values found under Steps (*b*) and (*c*).

Example 6.—An open transit-tape traverse approximately 1 mile long is to be run with a total permissible error of displacement of 1.0 ft. The ground is rolling with an average slope of about 6%; it is partly wooded and partly open so that for one-half the distance the tape is held unsupported and for the other half it is held on the sloping ground; the shape of the traverse is sketched as shown in Fig. 2. It is required to write specifications for the field work involved:

(*a*) For this traverse an equal amount of permissible error will be assigned to distance and to angles. Accordingly, by Equation (2),

$$1 \text{ ft.} = \sqrt{E_L^2 + E_A^2}$$

or,

$$1 \text{ ft.} = 2\,E_L^2$$

hence,

$$E_L = E_A = \pm 0.7 \text{ ft.}$$

(*b*) By arranging the computations as shown in Table 4, an estimate of the distribution of various chaining errors is obtained.

(*c*) It is assumed that systematic errors in measuring angles will be eliminated in the field and the permissible error will be calculated for accidental errors only. The values of the radial distances, *r*, are estimated; hence,

$$E_A = \pm 0.6 \text{ ft.} = e_a \sqrt{2\,800^2 + 2\,600^2 + 1\,600^2}$$

$$e_a = \pm \frac{0.6}{4\,100} = 0.00015 = \pm 30''$$

(*d*) According to the values assigned to the various sources of error under Steps (*b*) and (*c*), the following specifications will apply to the field work:

The length of the tape (E_l) shall be known within $\pm$ 0.005 ft.

The temperature of the tape (E_t) shall be determined within 15° Fahr.

The slope of the ground (E_g) shall be estimated correctly within an average error of 1 per cent.

The tension on the tape (E_s) to compensate for sag (weight, 1½ lb.) shall not vary from the standard tension (12 lb.) by an average error greater than 3 lb.

TABLE 4.—COMPUTATIONS FOR DETERMINING CHAINING ERRORS IN EXAMPLE 6.

Source.	Kind.	Amount, q.	q^2.
E_l	Systematic	$0.005 \times 33 = \pm 0.16$	0.03
E_t	Systematic	$0.01 \times 33 = \pm 0.33$	0.11
E_g	Accidental	$0.06 \times \sqrt{25} = \pm 0.30$	0.09
E_s	Accidental	$0.03 \times \sqrt{25} = \pm 0.15$	0.03
E_p	Neglect		....
E_o	Neglect		....
E_m	Accidental	$0.05 \times \sqrt{52} = \pm 0.35$	0.12
$\Sigma q^2 =$			0.38

$$E_L = \pm 0.6 \text{ ft.}$$

Errors due to variations in pull (E_p) may be neglected.

Errors due to variations from true alignment (E_o) may be neglected.

The positions of the ends of the tape shall be marked in such a manner that the average error (E_m) shall not exceed $\pm$ 0.05 ft.

The average error (E_a) in measuring the angles shall not exceed $\pm$ 30″.

STADIA MEASUREMENTS

Analysis.—The measurement of horizontal distances by the stadia method is affected by the systematic errors in the determination of the interval factor, K, differential refraction, inclination of the rod, etc., and by the accidental errors of reading the rod intercept, S, the vertical angle, α, etc. The effects of these errors, both for closed and for open traverses, will be similar in nature to those described for chaining.

The stadia formula for the horizontal distance is,

$$\int L = K S \cos^2 \alpha + (F + c) \cos \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

in which, L is the distance; S, the rod intercept; K, the factor interval; α, the vertical angle; F, the principal focal length of the objective lens; and c, the distance from the objective lens to the vertical axis of the instrument. The value, $(F + c) \cos \alpha$, is negligible and will be disregarded.

According to Equation (4),

$$E_L = \sqrt{(e_k S \cos^2 \alpha \times N)^2 + (\sqrt{N} K e_s \cos^2 \alpha)^2 + (\sqrt{N} K S e_a \sin 2 \alpha)^2}$$

in which, E_L is the total probable error, and N is the number of stadia readings.

Specifications.—The specifications for any transit-stadia traverse may be prepared by the following procedure (see Steps (*a*) to (*d*), page 2650): (1) Decide on the total permissible error; (2) assume average values for S and α and the probable errors for K, S, and α; namely, e_k, e_s, and e_a; (3) compute the total probable error; (4) revise the assumed values of the probable errors, if necessary, to meet the required degree of accuracy; and (5) write specifications for field work.

Example 7.—It is desired to measure the length of the traverse shown in Fig. 2 by the stadia method such that the probable error of displacement of the point, E, shall not exceed $\pm$ 10 ft. Write specifications for the field work:

(1) The permissible probable error is $\pm$ 10 ft.

(2) The average values are assumed to be $S = 5.00$ ft.; $\alpha = 3°$; $e_k = \pm 0.3$; $e_s = \pm$ 0.03 ft.; and $e_a = \pm$ 02′.

(3) In this example the error, e_k, is a systematic error, and e_a and e_s are accidental errors. Since the first term under the radical represents the systematic error, n, for this term, will be $\frac{33}{5} = 7$, and for the second and third terms, n, will be $\frac{52}{5} = 10$. Hence,

$$E_L = \sqrt{(0.3 \times 5.00 \times 0.999^2 \times 7)^2 + (\sqrt{10} \times 100 \times 0.03 \times 0.999^2)^2 + (\sqrt{10} \times 100 \times 5.00 \times 0.0006 \times 0.11)^2}$$

$$= \pm \sqrt{10^2 + 9^2 + 0.1^2} = \pm 14 \text{ ft.}$$

(4) The calculated value $\pm$ 14 ft. is greater than the permissible amount of $\pm$ 10 ft. It is noticed that the largest share of the total error is caused by the error, e_k; hence, it is assumed that by a more careful determination this is reduced to $\pm$ 0.1 ft.; it is also noticed that e_a yields only a very small error, and it will expedite the field work to increase this permissible error to $\pm$ 5′. Using the revised values,

$$E_L = \pm \sqrt{3.3^2 + 9^2 + 0.3^2} = \pm 9.5 \text{ ft.}$$

(5) The specifications for the field work are:

(*a*) The stadia factor interval shall be determined within a maximum error of $\pm$ 0.1.

(*b*) The average error in reading the rod intercept shall not exceed $\pm$ 0.03 ft.

(*c*) The average error in reading the vertical angles shall not exceed $\pm$ 05′.

Remarks.—Results determined in Example 7 show that the accuracy of stadia measurements is increased by reducing the systematic errors, and that, for small vertical angles, the effect of the error, e_a, is quite negligible. For large angles, however, the analysis gives a method for determining the required degree of precision in all factors.

Stadia Leveling

The procedure for preparing specifications for the work of stadia leveling is the same as for stadia traversing.

Example 8.—It is desired to run a line of stadia levels 5 miles long with a permissible error of closure of ± 3.0 ft. Write specifications for the field work:

(*a*) The permissible error of closure is ± 3.0 ft.

(*b*) Since by the methods used in stadia leveling all errors become accidental in kind and, therefore, compensative, the average permissible error for a single reading may be calculated. Thus,

$$e_s = \frac{E_t}{\sqrt{n}} \qquad (8)$$

in which, e_s is the probable error of a single reading; E_t, the total probable error; and n the number of observations. For a traverse 5 miles long and for average sights of 400 ft., the number of sights will be about 65. Hence,

$$e_s = \frac{3.0}{\sqrt{65}} = \pm 0.37 \text{ ft.}$$

(*c*) Assume the stadia constant, K, to be known with a probable error of ± 0.3 ft.; the rod intercept to be read with a probable error of ± 0.03 ft.; and the vertical angle to be measured with a probable error of ± 02′. Accordingly, $e_k = \pm 0.3$ ft.; $e_s = \pm 0.03$ ft.; and $e_\alpha = \pm 02'$.

The stadia formula for the difference in elevation, V, is given by the relation,

$$V = \frac{1}{2} K S \sin 2\alpha + (F + c) \sin \alpha$$

The quantity, $(F + c) \sin \alpha$, will be neglected in the following calculations.

(*d*) By Equation (4) and by assuming the average rod intercept to be 4.00 ft., and the average vertical angle, α, to be 3°;

$$e_s = \sqrt{\left(\frac{1}{2} e_k \times s \times \sin 2\alpha\right)^2 + \left(\frac{1}{2} K e_s \sin 2\alpha\right)^2 + \left(\frac{1}{2} K s e_\alpha 2 \cos \alpha\right)^2}$$

$$= \sqrt{\left(\frac{1}{2} \times 0.3 \times 4.00 \times 0.11\right)^2 + \left(\frac{1}{2} \times 100 \times 0.03 \times 0.11\right)^2 + \left(\frac{1}{2} \times 100 \times 4.00 \times 2 \times 0.0006 \times 0.99\right)^2}$$

$$= \sqrt{0.07^2 + 0.17^2 + 0.24^2} = \pm 0.30$$

It is seen that the assumptions in Step (*d*) yield a probable error, $e_s = \pm 0.30$ ft., which is less than that required under Step (*b*). Accordingly, the probable error in reading the rod may be increased to ± 0.04 ft. Using this value, the total probable error, $e_s = \pm 0.33$ ft., which is satisfactory.

(*e*) The specifications for the field work are:

1.—The stadia constant, K, shall be determined with a probable error not exceeding $\pm$ 0.3.

2.—The probable error in reading the rod shall not exceed $\pm$ 0.04 ft.

3.—The probable error in reading the vertical angles shall not exceed $\pm$ 02′.

Conclusion

The actual behavior of errors agrees more nearly with their theoretical characteristics the more carefully the measurements are made. In other words, if the conditions under which the measurements are made, are carefully controlled, the systematic and accidental errors can be more perfectly classified than if the control of the measurements is less complete. Accordingly, theoretical and actual results, as regards the errors in surveying measurements, will agree more closely under the former than under the latter conditions. However, for the relatively crude measurements of low precision it is believed that the speed of the work can be increased and the character of the results greatly improved by the judicious use of the methods here presented.

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COMMENTS ON THE DESIGN OF SLUDGE DIGESTION TANKS*

By Richard H. Gould,† M. Am. Soc. C. E.

Synopsis

The digestion of sewage solids is brought about by certain fundamental processes that are common in Nature. These were utilized by Man for the treatment of sewage before the development of the science of bacteriology and before any proper appreciation was had of their nature. Metcalf‡ has given an excellent outline of the use of digestion in the cesspools of London and Paris early in the Nineteenth Century, of the application of the principles involved to small household appliances, and, in the latter part of the century, to the septic tank.

The septic tank has been largely superseded by the Imhoff tank, and in the past few years there has been a decided movement toward the digestion of sewage solids in separate tanks. These developments have been brought about in large measure by efforts to minimize the nuisances attendant on the treatment of sewage; to make the tank effluent more amenable to further treatment; and to reduce the costs of construction and operation.

The purpose of this paper is to indicate the manner in which the experiences of past years in the use of tank treatment and the recently developed scientific knowledge of the bio-chemical actions, are being applied to the design of sludge digestion tanks.

Experiences with Septic Tanks

The long use of septic tanks and cesspools has shown that the anaerobic digestion of sewage solids will reduce these solids very largely in bulk and

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‡ "The Antecedents of the Septic Tank", Leonard Metcalf, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. XLVI (1901), p. 456.

will leave a residue of an inert, odorless character. This resulting sludge can be handled with relative ease and dried readily. Thus, the septic tank marks a distinct advance over the plain sedimentation tank and brings about a reduction in operating costs through easier sludge handling. Because of the difficulty of properly disposing of the sludge from plain sedimentation tanks the development of odors following septic treatment was probably not increased.

Certain evils, however, attended the use of the septic tank. The sewage became highly charged with odorous gases of decomposition, which were often liberated to the air during subsequent treatment. The effluent did not re-act so easily to aerobic treatment as fresh sewage effluents. During warm weather, at times of heavy gas formation in the tanks, the effluent was contaminated with suspended matter, often to an amount in excess of that in the raw sewage. The usual experience was that considerable odor was developed in the tank itself, both from the gases rising out of the liquid and from those produced in the mats of scum on top.

Experiences with Imhoff Tanks

The advantages of the digestion of sewage solids, as shown by the septic tank, were utilized to even better advantage in the Imhoff tank. While retaining the anaerobic decomposition of solids, this tank permitted the flowing sewage to retain its freshness by confining it to a special compartment separated from the decomposing sludge and by allowing the freshly deposited solids to pass to the sludge compartment by gravity through slots constructed so as to prevent the contamination of the flowing sewage by gas-lifted solids. Only the oldest and most thoroughly digested sludge is removed from good Imhoff tanks, and is probably somewhat better than that from septic tanks. The control of digestion is such that no odorous gases are liberated from the sludge compartment. A properly designed and operated Imhoff tank is still considered eminently satisfactory for the handling of sewage solids and the preliminary treatment of sewage.

Although there are many successful Imhoff tank installations, others to a considerable number in the aggregate have given disappointment. Perhaps in the majority of cases this failure can be traced to faulty operation, but often the original design has been at fault. Too often units for capacities that have proved satisfactory, have been applied to new designs without proper appreciation of the loadings, form of tanks, and climatic conditions under which the first results were obtained. Eddy,* in an exhaustive comparison of four Imhoff tanks, two of which gave satisfactory results, summarizes reasons for differences in behavior under twenty-five separate headings. The multiplicity of these considerations, many of which are entirely neglected by some and interpreted in accordance with individual bias by others, seems to explain adequately the reason why there are so many poor designs. Fortunately, later researches have tended to minimize some of the uncertainties formerly existing.

* "Imhoff Tanks—Reasons for Differences in Behavior," by Harrison P. Eddy, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. 88 (1925), p. 465.

Granted adequate design, there are still reasons in some cases for a search for better appliances. The Imhoff tank with its two stories, one above the other, is a deep structure. The usual location for disposal plants is in low ground with a high ground-water level. The result is heavy construction costs for deep tanks. The fact that the sedimentation compartment and the sludge compartment of an Imhoff tank are combined in one unit makes it impossible to change the relation between the two. It is sometimes difficult to estimate in advance the exact flow to be treated and the sludge quantities to be cared for; indeed, these factors may change their relation after a number of years of operation. The tank, however, is fixed and cannot be altered to correspond. The temperature in the sludge compartment is essentially the same as that of the flowing sewage. In northern climates the cold winter sewage retards digestion greatly. Furthermore, it is not practical to heat the digestion compartment artificially, and gain the resulting benefits.

Early Example of Separate Digestion

The digestion of sludge in tanks separated from the flowing sewage has been successfully accomplished in England and in Germany. In America the first notable example on a large scale was at Baltimore, Md. There, following unfortunate results with Imhoff tanks, separate sludge digestion was developed. The early work did not have the advantages of previous large scale experience or of scientific research. Certain unanticipated results were obtained. At times, sludge that was expected to settle came largely to the surface; and there were other difficulties in handling the sludge, in lack of capacity, and in odor production. It was demonstrated, however, that separate digestion was possible and that its costs were reasonable. Under the conditions and arrangements provided, large unit capacities were found to be necessary.

Research on Digestion Problems

A most promising step toward better design of digestion tanks lies in the scientific research carried on within the past few years. The important work done at the New Jersey State Sewage Experiment Station at Rutgers College, New Brunswick, N. J., by Dr. Willem Rudolfs has been checked, in many respects, by parallel studies at Harvard University by Fair and Baity under the Rockefeller Foundation Fellowship. Other experimenters have been at work elsewhere in the United States, as well as in Germany and in Russia.

In carefully controlled laboratory experiments, it has been possible to separate the many variable factors that affect digestion and ascribe limiting results to each factor. It should be recognized that the course of digestion in the sludge compartment of an Imhoff tank and in a separate digestion tank is essentially the same, so that knowledge of the surrounding conditions can be applied with equal force to either type of structure. The form of the works may be different and this may alter environmental conditions, but the fundamental processes are the same in each case.

Nature of Digestion

Laboratory experiments have demonstrated that in the course of digestion the nature of the early products is acid, followed in the later stages by alkaline products. The most advantageous digestion occurs within a narrow range of acidity and this is best expressed in terms of the hydrogen-ion concentration, as pH-values. Should the pH-value become much less than 7.3, acid foaming may occur; and if much more, that of an alkaline nature may result. Odors result from either extreme condition. Thus, by controlling the pH-value within a narrow range the desired type of digestion—either liquefying or gasifying—may be secured.

Measurements of gas production have been made, and these, in conjunction with actual measurements from tanks in service, indicate that methane gas in worth-while quantities can be collected. As would be expected, the temperature has a large effect on the rate of digestion. Oxygen was found to be detrimental to anaerobic digestion, and to aid, perhaps, in odor production.

Practical Application

The essentials for optimum digestion are few in number and easy to apply. The question of reaction control in tanks of adequate design will normally take care of itself. It is only necessary to ensure that sufficient quantities of sludge in the later stages of digestion, when alkaline products are being given off, are in the tank, to counterbalance the acid production of freshly added solids. This is the criterion that should control tank loading. It is not the volume of tank space available, but the actual presence of a definite quantity of sludge that is important. Dr. Rudolfs believes that the addition each day of fresh solids to the extent of 2% of those already in the tank, both on the dry basis, is permissible without adversely affecting the optimum conditions for digestion, when the temperature is about 70° Fahr. The value of the artificial control of the reaction by the use of lime has been demonstrated in restoring tanks to proper operating conditions. This permits loading beyond that indicated.

The laboratory work is based on the quantity of destructible organic matter in the solids to be treated. The danger of using uniform per capita allowances for sludge digestion space has been frequently shown. Such a unit is convenient and has the value of time-honored use, but it should be defined in such a way as to correspond with sludge of the volume and character as that deposited from sewage of normal strength under the usual settling tank conditions. On this basis laboratory results showed the digestion capacity required for a particular case to be about 0.8 cu. ft. per capita, provided the reaction and temperature conditions were controlled, whereas about 2.5 cu. ft. per capita would be necessary without such control. This is a ratio of about 1 to 3 in favor of controlled digestion.

Comparison of Laboratory and Field Results

Engineers acquainted with Imhoff tanks or digestion tanks, in operation under different conditions, will probably agree that the results shown by the

laboratory tests through the control of digestion are not improbable. In comparing such tanks it should be borne in mind that the sludge capacity for the Imhoff tank is computed as that part below the slots, or even 18 in. below, whereas that of a sludge digestion tank includes the entire water volume. The space for floating sludge in an Imhoff tank may add but little to its digesting capacity; but there is also a space for liquid in most digestion tanks which must not be neglected in any computations for required capacities.

An example of a plant operating under unusually favorable conditions with low digestion capacities is the original installation at Dallas, Tex., designed by James H. Fuertes, M. Am. Soc. C. E. These Imhoff tanks, beginning in January, 1917, operated satisfactorily up to a loading beyond that for which they were designed. The digestion space below the slots was less than 0.5 cu. ft. per capita as determined by a careful population check, modified somewhat by the volume of suspended solids actually being retained in the tanks. At this loading, however, well-digested sludge was obtained. It was inodorous and could be removed from the drying beds after three to four days of good weather. For a comparison with digestion tanks, the total space in the digestion compartments of these tanks (including that for floating sludge) was equivalent to about 0.9 cu. ft. per capita. It should be noted that the average seasonal temperatures were relatively high and that, in addition, a considerable volume of hot water came from artesian supplies. The range of temperature in the tanks is not known. The form of the sludge wells at Dallas is such that very nearly the entire capacity is available for digestion. Each well serves but one sedimentation chamber.

The loading at Dallas was much higher than is common in America, but it will be recalled that the early recommendations by Dr. Imhoff, for digestion capacities for domestic sewage from separate systems, were not greatly in excess of this quantity. These recommendations were based on the operation of similar plants in the Emscher District, in Germany. The writer has seen a number of those plants in successful operation.

A brief comparison of the per capita digestion capacity at Dallas with that at other more northerly locations is shown in Table 1. This confirms the conclusion that by suitable control it is possible to reduce the required digestion capacity to one-third that otherwise necessary.

Additional confirmation of the conclusions indicated in Table 1, is furnished by results secured at the Joint Disposal Works of Plainfield, N. J. In this case separate digestion tanks, constructed to handle sludge formerly treated in Imhoff tanks, are provided with floating covers, gas collection appliances, and means for artificial heating. John R. Downes, Superintendent and Designer, states that the new tanks have produced good sludge, without odors, under conditions of operation with a continuous loading such that there was only about 0.75 cu. ft. of digestion space per capita. The temperature range was from 65° to 70° Fahr. Formerly, unsatisfactory results were obtained with this same sewage in Imhoff tanks with a nominal digestion capacity below the slots of 1.49 cu. ft. per capita.* It is doubtful in this latter case whether all this space could be used to full advantage.

* *Transactions*, Am. Soc. C. E., Vol. 88 (1925), p. 486.

Considerations Affecting Design

How far the possibilities of digestion control may be utilized depends to a large extent on the intelligence with which the plant will be operated and the general policy pursued in the construction of the works. From a theoretical standpoint it is distinctly economical to maintain relatively high temperatures and to control the reaction of the contents. The saving in interest on the extra cost of larger tanks would pay many times over for the heating and lime necessary.

TABLE 1.—Comparison of Capacities.

Plant.	Sludge capacity, in cubic feet per capita.	Ratio, to Dallas, Tex., as base.
Imhoff Tanks (Capacity to Slots):		
Dallas, Tex.	0.5	1.0
Requirements, New York and New Jersey State Boards of Health	2.0	4.0
Fitchburg, Mass.*	1.88	3.76
Rochester, N. Y.*	2.49	5.0
North Shore Sanitary District, Illinois†	3.0	6.0
Digestion Tanks (Capacity to Water Surface):		
Dallas, Tex.	0.9	1.0
Baltimore, Md.‡	3.57	3.97

* *Transactions*, Am. Soc. C. E., Vol. 88 (1925), p. 486.
† *Engineering News-Record*, September 18, 1924.
‡ *Loc. cit.*, July 29, 1926.

It has been demonstrated that methane gas in worth-while quantities can be collected from digestion tanks. The heating value of this gas is probably more than enough to maintain the desired temperatures. In one case where it is proposed to return surplus activated sludge to the digestion tanks it is estimated that sufficient power can be developed for a system of partial activation. More important than these possible economies are satisfactory operating conditions and results. It is good engineering to allow a certain margin in capacity to assure these ends. Unless the plant is to be operated with intelligence it will be difficult to realize all the possible advantages.

In arriving at the digestion capacity to be provided the question of sludge removal must be carefully considered. For operation at the maximum rating, the loading of fresh solids should be uniform. The removal of sludge throughout the year is a distinct advantage in the operation of the tank itself. This is rarely possible under the usual climatic conditions. If sludge cannot be removed at all times additional capacity must be provided in the tank, or elsewhere, to tide over these shortcomings. The improvement in methods of sludge handling and sludge drying is thus of great importance and has a direct bearing on tank design.

After the required digestion capacity is determined, a form of tank must be selected that will give this capacity in effective space. A flat-bottomed tank does not adversely affect digestion, but may contain dead pockets (as in the corners), that will gradually become filled with inert material and thus may not be considered as effective digestion space. The desirability of providing multiple outlets or mechanical means for maintaining the usefulness

of the entire tank capacity can best be determined by a study of the relative costs involved. The admission of fresh solids to a tank should be controlled so as to distribute them fairly evenly throughout the active zone of the tank and to cause their thorough seeding with the older sludge. A concentration of fresh solids in isolated points is to be avoided.

The preponderance of evidence seems to be strongly in favor of providing covers for digestion tanks. One of the major reasons is to suppress odors. In an open tank a certain amount of oxygen comes in contact with the digesting material and this has been shown to retard digestion and tend, if anything, to increase the odors. If the reaction is not correct a dense scum may form which becomes partly dried on exposure to the air and is the source of objectional odors and flies.

A number of different types of covers have been used or proposed. A simple elevated cover somewhat above the surface prevents the spreading of odors to a certain extent. As usually operated, however, this form admits air to the tank when sludge is drawn, with consequent disadvantage to the digestion process, and possible formation of an explosive mixture of gas. This type is not particularly well adapted to the collection and utilization of the gas produced, as it may permit contamination with air, when sludge or liquid is withdrawn.

Suppressed covers, by keeping the scum submerged, prevent its drying and aid in its digestion. This form has the disadvantage that, in case the tank tends to foam, resulting conditions are aggravated, as the gas and foam must pass through a constricted outlet smaller than the gas vents of an Imhoff tank. The admission of fresh sludge causes an equivalent displacement of liquid which may contain an appreciable quantity of suspended matter. It has appeared desirable in some cases to provide a separate compartment to store this overflow.

A third type, perhaps the most flexible, is the floating cover such as is installed at the Plainfield works. It rises and falls with the admission and withdrawal of sludge, thus excluding oxygen at all times and ensuring that the gas is uncontaminated. The cover can be operated so as to submerge such scum as is formed, or should foaming develop the vertical displacement of the cover provides space for its accommodation. A modified design has been proposed, much in the form of the ordinary gas-holder, providing a cover and also space for storing the gas produced. For practical utilization of the gas, some such device seems desirable to tide over inequalities in the rates of production and use.

Fresh solids admitted to a digestion tank undergo a reduction in volume by liquefaction and gasification. The digested sludge through its changed character is much more compact than fresh sludge and increasingly so the longer it is allowed to stay in the tank. The sludge withdrawn always has a lower water content than that added. This means that, in order to maintain an adequate volume of old sludge in a tank, liquid must be withdrawn from time to time. By careful selection of the point of withdrawal it is possible to obtain liquid with but little suspended matter, which may be returned to the plant influent without causing much trouble. The quantity of this liquid is

a very small part of the total flow; if it is not so disposed of, it may be filtered on a sand bed.

A separate sludge well, in connection with digestion tanks, is often of distinct advantage. Surplus liquid can be drained to it from the tanks. The solids can be settled out or floated to the surface by the use of alum, the clear liquid pumped to the main influent of the plant, and the solids returned to the digestion tanks. Such a well also furnishes a convenient place for the adjustment of the reaction by circulating sludge from the tanks through the sludge well, adding the necessary lime at this point. When sludge drawn from the sedimentation tanks has a high water content, the sludge well may be used for its concentration. This will be particularly advantageous during cold weather, avoiding the necessity of heating excessive volumes of cold water.

The design of digestion tanks cannot be divorced from that of the other disposal works, nor from the degree of attention that the works will receive when built. The rate and character of the loading, the length of the season over which sludge may be drawn, and the temperatures that can be expected are all factors of vital importance. If it is probable that the plant will not receive careful attention, it may be advisable to add appreciably to the capacity. A nice balance must be struck between the benefits to be secured and the costs of construction and operation necessary to bring them about. A solution that is proper in one case, might be quite inadequate elsewhere.

Typical Designs for Digestion Tanks

The designs for digestion tanks shown in Figs. 1 to 6 illustrate the general trends. While a number of interesting developments are shown, no attempt has been made to indicate all types of tanks built or proposed.

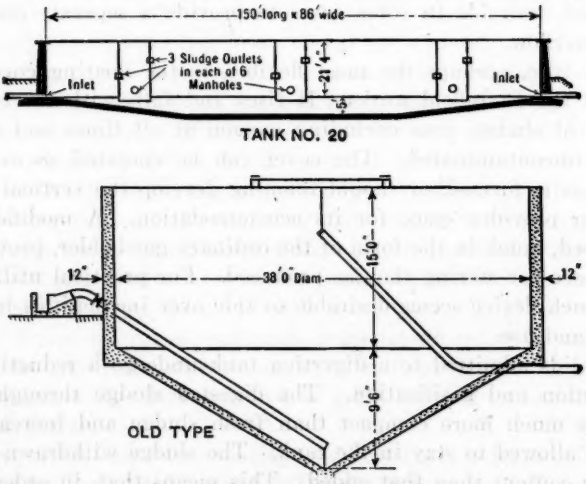

Fig. 1.—Baltimore, Md., Tanks.

The tanks at Baltimore, Md. (Fig. 1) are the largest and, at the same time, one of the first examples of separate digestion tanks in America. They use what might be called uncontrolled digestion. So far as is known, no

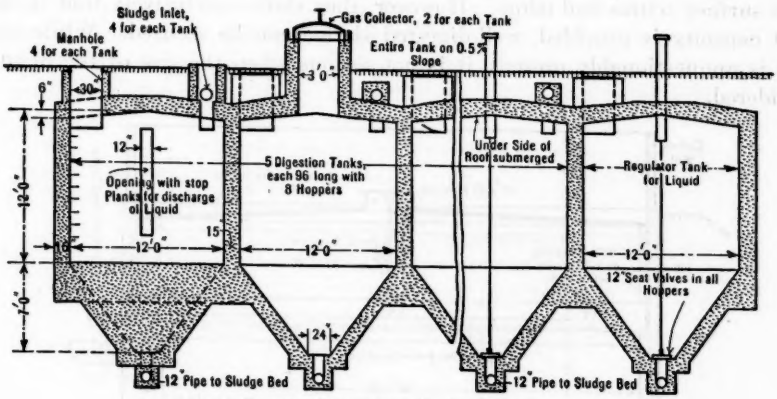

FIG. 2.—BOONTON, N. J., TANKS.

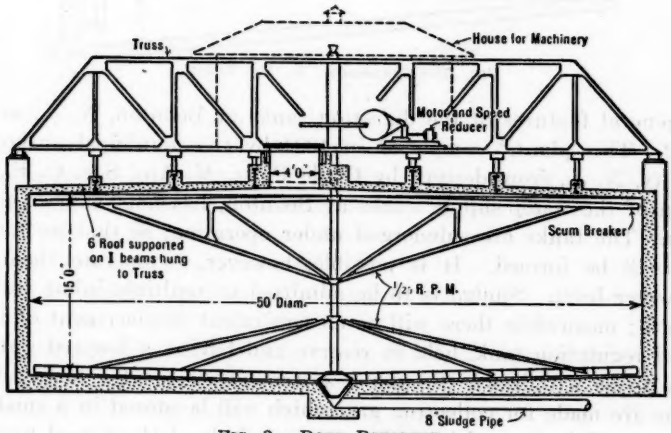

FIG. 3.—DORR DIGESTER.

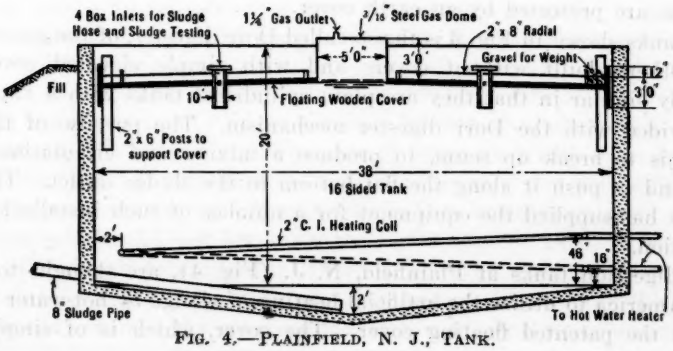

FIG. 4.—PLAINFIELD, N. J., TANK.

especial attempt has been made to limit temperatures and reactions, or to suppress surface scums and odors. However, they show conclusively that if sufficient capacity is provided, well-digested sludge can be secured. While some odor is unquestionably present, it is not serious when the size of the plant is considered.

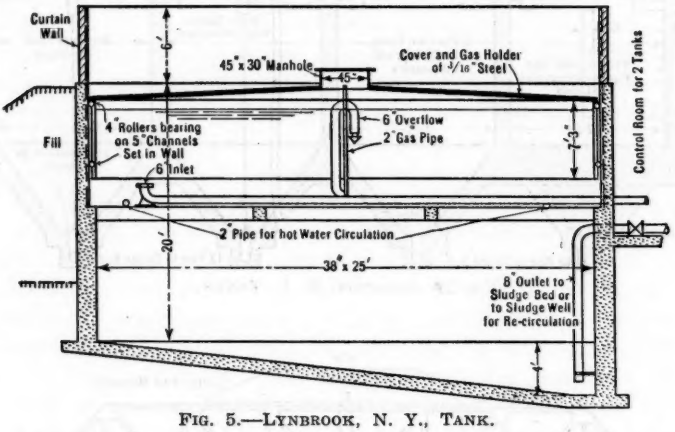

FIG. 5.—LYNBROOK, N. Y., TANK.

The general features of the digestion tanks at Boonton, N. J., are shown in Fig. 2. This plant,* completed in 1924 by the municipal authorities of Jersey City, N. J., from designs by Clyde Potts, M. Am. Soc. C. E., for the protection of the water supply works at Boonton, has not yet been placed in operation. The tanks are submerged under operation, so that no tough mat of scum will be formed. It is possible, however, to operate them with a lowered water level. Sludge is to be admitted at multiple inlets throughout their length; meanwhile there will be an equivalent displacement of liquid to a so-called regulation tank, held in reserve and having a lowered water level. Sludge is to be withdrawn through a system of steep-sided hopper bottoms. Provisions are made for collecting gas, which will be stored in a small holder near-by, and will be burned in a glass-covered sludge bed, or used to raise the temperature of the tanks, should it later be decided to install a heating system. The tanks are protected by an earth cover.

The tanks shown in Fig. 3 is the so-called Dorr digester, of the gas-collector type. Others, built without covers and with simple elevated covers, are essentially similar in that they are plain cylindrical tanks with a flat bottom and provided with the Dorr digester mechanism. The purpose of this contrivance is to break up scum, to produce a mixing and circulation of the sludge, and to push it along the flat bottom to the sludge outlet. The Dorr Company has supplied the equipment for a number of such installations now in operation.

The digestion tanks at Plainfield, N. J. (Fig. 4), are thought to be the first in America to utilize the artificial heating of sludge by hot-water circulation and the patented floating cover. The cover, which is of simple wood

* *Public Works*, July, 1925.

construction, rises and falls with the admission or withdrawal of sludge or liquid and permits the collection of gas in the central dome. No trouble has occurred from scum, odors or foaming sludge. Sludge is admitted to the tanks through hose lines inserted in any one of four inlets in the cover, and is withdrawn through a single central pipe. The tanks were built at a very low cost.

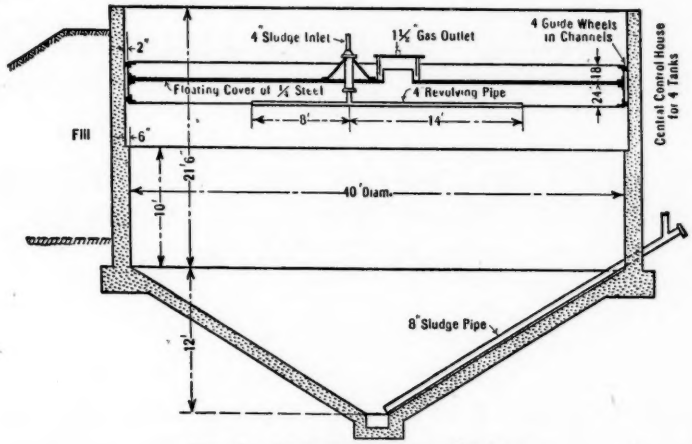

FIG. 6.—SPRINGFIELD, ILL., TANK.

The design for Lynbrook, N. Y., by Mr. Fuertes, is shown in Fig. 5. These tanks were intended both for primary solids and for surplus activated sludge. Provisions are made for heating the sludge, for circulating it, by pumping, for mixing, and for reaction control. The unusual cover, of steel and in the form of a gas-holder, is to store the gas produced for utilization about the plant as required.

The design for Springfield, Ill., by the firm of Pearse, Greeley and Hansen (Fig. 6), is another example of an attempt to provide means for controlling digestion and collecting gases. A floating steel cover is proposed, with special means for introducing and distributing the sludge. The elevation of these tanks, as is true of all the examples cited, is not dependent on that of the flow line of the outfall sewer, so that appreciable economies in construction costs are possible by avoiding deep excavations in water-bearing soil.

FUTURE DEVELOPMENT

With the development of more accurate knowledge of the nature of anaerobic digestion, this process seems capable of being used with more intelligence than in the past. It furnishes an economical method for the inoffensive disposal of organic wastes and will undoubtedly have broad application. Information developed in the last few years has had a marked affect on the trend of design of sludge digestion tanks. There is, however, much to be learned as to the absolute capacities required under different conditions. To this end engineers should continue the generous publication of accurate operating data.

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RELATION OF THE LANDSCAPE ARCHITECT TO THE ALLIED PROFESSIONS ENGAGED IN CITY PLANNING*

By Arthur A. Shurtleff,† Esq.

In the many allied professions engaged in city planning are men who devote their lives to the law, social betterment, statistics, engineering in specialized fields, to sculpture, the graphic arts, architecture, and landscape architecture. Exceedingly important parts are played by men of the press, legislature, finance, business and industry. The speaker will attempt to outline the relation of the Landscape Architect to only two of these professions—Engineering and Architecture.

Measured by the age of American cities and by the existence of these three professions in the United States, the relationship is one of the oldest and most fruitful which has united any group of professional men. By tracing, even superficially, the history of these professions with regard to the amazing changes which have taken place during a century, it is possible to see how the ties were formed between men in these fields.

These ties developed with the growth of the professions and were not imposed by agreement. The agreements which subsequently bound the three professions together for the convenience of the Government during the World War were merely applications of the methods of working together which were evolved among the professions during their many years of previous relations. The landscape architects, the engineers, and the architects took the governmental harness as a familiar hitch-up, and sprang to the work to be done in the familiar way without loss of time or energy.

Engineering of a professional kind in this country began with the construction of the first permanent forts, dams, and canals. Later, when railroads were built, new kinds of engineers with special training met these

Note.—Written discussion on this paper will be closed in March, 1929.

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† Landscape Archt., Boston, Mass.

needs. Still later, when public water-supply and sewer systems supplanted the private pump and cesspool, another type of needs brought new types of engineers to the fore. The realm of the surveyor, millwright, and general engineer, was enlarged as the newer men began to specialize and as the old men tried to hold to general practice. When they were urged, surveyors merely ran out parallel lines for streets quite regardless of contours or future traffic needs. That procedure suited public opinion perfectly in those days. City planning in most parts of the country was "swallowed up" in checkerboards of new streets, buildings, water pipes, sewers, and rails, to which was soon to be added a tangle of electric wires.

Architecture in the United States began with the very early and excellent work of well-trained housewrights, carpenters, and masons, who planned and built with their own hands, following the best traditions of Europe. A few of these men and their immediate successors called themselves architects, but that title was not in general use in 1850. Some of these men were aware of the need for design in city plans as illustrated by the history of Washington, D. C., and a few other cities which were deliberately laid out with a consideration of good appearance. As a whole, however, this profession, like that of engineering, was preoccupied in the urgent local building problems of the new era and devoted little attention to city planning which, in those days, would have seemed a highly academic subject if it had been brought up by main force for discussion. Landscape architecture in this country also began with the transplanting of the traditions of England, France, and Germany. The European work of Repton, LeNotre, and Puckler-Muskau made an impress on the design of small and large estates, on a few cities, and on parks in this country.

The first great opportunity of the landscape architect in city planning came about in an exceedingly unexpected way. It is equally correct to state either that the opportunity was given to the landscape architect or that he took it. In the Fifties, or thereabouts, there were few or no city parks and playgrounds in American cities. Here and there open spaces existed, it is true, but they were not parks in the sense with which that word is used to-day for the great city populations. They were comprised of a few large commons, training fields, and "greens" and a few trivial little parks made for the delight of fashionable ladies and gentlemen interested in flowers and sun-dials. The need for parks in the sense with which that word is used to-day had not made itself felt.

At this time when the engineers and the architects were preoccupied in their new fields of usefulness, a cry came for real city parks, but the demand was not very seriously "taken to heart". No one realized, at that time, the part that parks were destined to play in town planning. The landscape architects undertook to handle this new, serious phase of old work. These men were ready, their ability was known, and their practical knowledge of the materials of their art was evident from previous smaller work. Central Park, in New York, N. Y., was a conspicuous example of one of the first and largest of the city parks which were designed in this new era by landscape

architects. In other cities the number of large parks of attractive design increased rapidly to meet the needs of growing populations.

This epoch was less than half over when the need for comprehensive systems of parks rather than for single individual parks gave a new impetus to the activities of landscape architects. In many cities and metropolitan areas the enthusiasm for large well-distributed parks led to the creation of notable well-planned systems distinguished both by the beauty of their landscapes and by the extent of ground which they embraced. This was a city planning problem which required a practical knowledge of topography, materials, populations, and of the transportation needs of that era. Public opinion pretty generally chose the landscape architect to design these systems of parks, not merely because he had succeeded with single parks, but because he had attained results attractive to the eye. He had earned the reputation of being able to attain beauty as well as convenience. Then, as now, the American public demanded this quality in a park system. The art of arranging such ground in relation to surrounding streets, private properties, schools, public buildings, and to the topography and the exposure of sites, rapidly developed and led to an increase in the number of landscape architects, to the creation of local professional societies in the larger cities, and to an American Society of Landscape Architects.

With the popular demand for park systems, the need for connecting parkways followed somewhat unexpectedly about 1890. This was still in the era of horse-drawn vehicles. The relation between the city plan and these pleasure routes, and their relation to the sanitary improvement of river, stream, and pond borders within or near cities, was exceedingly intimate. These were new problems, and the men to whom they were delegated for solution were forced into new lines of thought and of procedure. Without a rather full understanding of the whole plan of the city, a rational design for these pleasure-ways was out of the question. Hence, it was that these landscape architects were among the first group of men to "size up" city plans as they existed and to adapt them to the new demands for recreation and for long-distance and continuous routes for pleasure travel.

The recreation areas and the continuous parkway lines which these early landscape architects established in American cities are even now the most conspicuous features of these communities, and they are usually the most attractive. Although natural in the course of events, it is remarkable that the landscape architects who began as park designers found themselves planning these radical changes in the major plans of some of the largest cities and metropolitan districts. With the coming of the automobile these great parkways were discovered to be the only convenient long-distance, through routes of ample width and good gradient in the entire mesh of the closely built-up streets which had grown by mere accretion.

This amazing chapter in the history of American city planning could not have been realized if the work had lacked, during all these decades, the initiative and backing of the many groups of professional and business men previously mentioned. The work they accomplished reflects the needs and the ideals of this country rather than the ability of a single group of men.

The success of each stage of the work was vastly aided by the co-operative spirit of the engineers, architects, and the landscape architects. The landscape architects needed the help of the engineers who made topographical and other surveys, estimates of earthwork volumes, stabilities, run-offs, capacities, strengths, costs, and other basic data with regard to ground, water, and structures, and the mechanical execution of the work of construction. Public confidence was supported by the knowledge that able engineers were called in to help with important engineering matters.

Public confidence in the ultimate beauty of the parks and parkways was also supported by the fact that architects of known ability were called in to design the important bridges, field-houses, gateways, and other structures, the good appearance of which was essential to the attractiveness of parks. By far the greater number of these men, as workers in the Fine Arts, were conscious of the need of keeping such structures subordinate to the landscapes of the parks and appropriate in design to the uses which these new open spaces required. The most forward-looking architects realized fully that the loveliness of the parks and parkways was an aim in itself.

That strong friendships sprang up between engineers, architects, and landscape architects under these conditions of mutual dependence and aid was natural. The best parks of the country illustrate the results of this practical co-operation among men who whole-heartedly pooled diverse training, special abilities, and individual talents, toward the attainment of a single result. If parks are found which are not attractive or not sound from an engineering point of view, the assumption can fairly be made that these three professions were not able to render their full service in co-operation toward a good general plan.

The present is an interesting era. To-day, the Engineering Professions and the professions of the Fine Arts are forced into co-operation to meet a public opinion which passes final judgment and pays the bills. Cities must be made convenient structurally for physical needs, but, if they fail to be attractive to the eye, public opinion condemns them and proclaims its disapproval in the press, in popular gibes, and in the daily slang of a whole country. Human beings by the million continue to live in cities thus damned, but if the signs of the times can be read aright, that is not to be the fate of the populations of the cities of the future. The new populations intend to live in attractive cities, or else to seek attractive towns or villages. The day is fast approaching when a great city can no more afford to be ugly than a great industry can afford to place ugly goods on the market.

To find a place in city planning something more is needed of every one than this ability to see the relation of the parts of a city to the great whole and then to act in accordance with that insight. They must see themselves in similar perspective as single units among the many men who are working with this new vision. Without generous co-operation in modern city planning the work cannot be well done. Although it has been stated that the great names in city planning were strong-headed, overbearing personalities who succeeded by domination, the real record of these men shows that they were geniuses in patient co-operation to which they contributed first-rate ability.

Work is waiting for each of these allied professions if they are big enough to "deliver the goods" and if they can good-naturedly "take the gaff" involved in co-operative effort.

Public opinion, except in small cities or towns, has become "leery" of any one man or of any group of a single profession who asserts final opinions on a city planning project the structure and appearance of which and the relation of which to the amenities, the resources, and the general welfare of a great community involve the work of all the professions. This kind of public opinion in more enlightened communities shows itself by the care with which the professions are represented in the personnel of planning boards, advisory councils, and in the choice of special advisers in the fields of general engineering, sanitation, transportation, finance, landscape architecture, architecture, and the other fine arts through special representatives or through regularly constituted art commissions. In Washington, D. C., all these men are working together on the plan for that city.

The means for bringing these professions and these controls and aids to bear on great city planning projects to make them as perfect as possible is still clumsy and unsatisfactory, but the trend of public opinion in the matter is clearly manifest. The thorns which lie in the path of the progress of any great project which has not been thoroughly studied in its relation to attractive appearance as well as to utility are many, and they are large and sharp. They are largest and sharpest in the most well-informed communities. That fact is an encouraging sign of progress.

The relation which the landscape architect has borne to the engineer and to the architect in city planning has been intimate and creative for nearly a century. Public opinion supports him still in the principle which has been the foundation of his work from the beginning, that the good appearance of finished work is an essential of vital importance. Mere mechanical capacity to accommodate crowds or to provide exercise or to give volume and speed to streams of vehicles is not enough. Cities—whether old ones transformed for new uses, or new ones built for to-day—must give delight to the eye and to the spirit. That appears to be the city planning problem of 1928 to the solution of which public opinion turns to the landscape architect, to the engineer, and to the architect after three-quarters of a century of experience with them as co-operators with one another and with the other allied professions.

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ENGINEERING APPLIED TO NATIONAL PARKS*

BY STEPHEN T. MATHER,† ESQ.

Beginning in 1872 with the setting aside of the Yellowstone National Park "as a public park or pleasuring ground for the benefit of the people", the fundamental principle underlying the National Park System has been the preservation of scenery—the natural objects and wonders and their retention in their natural condition. Congress re-affirmed this principle in creating the National Park Service in 1916, by stating‡ that the Service, in its administration of the National parks and monuments, was "to conserve the scenery and the national and historic objects, and the wild life therein, and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations".

In order that the people might enjoy the National parks it was necessary that roads be constructed to and within them to permit access to their treasure troves. At first the roads in most parks were haphazard wagon roads, in existence at the time of their reservation, and it is the conversion of these old wagon roads into adequate automobile highways, or the construction of new roads, that forms one of the principal engineering problems confronting the National Park Service. This does not mean the establishment of a gridiron of roads nor over-development. Large areas must always be preserved in their wilderness character.

DEVELOPMENT OF THE YELLOWSTONE ROAD SYSTEM

Due to the foresight and engineering ability of the late Gen. H. M. Chittenden, U. S. A. (*Retired*), M. Am. Soc. C. E., who, as an officer in the Engineer Corps, was placed in charge of the road work in Yellowstone Park in 1883, the system of roads laid out in that park is now a standard

NOTE.—Written discussion on this paper will be closed in **March, 1929.**

* Presented at the Joint Meeting of the City Planning and Highway Divisions, New York, N. Y., January 19, 1928.

† Director, National Park Service, U. S. Dept. of the Interior, Washington, D. C.

‡ Act of August 25, 1916 (39 Stat., 535) establishing the National Park Service.

for general rational park road development. The main loop road, which embraces in a general circuit all the important centers of interest in the park, and the connecting gateway roads, are the work of General Chittenden. This system provides 303 miles of roads in an area of 3 348 sq. miles. For a number of years after 1883, Congress annually appropriated $40 000 for road work, part of which was spent in actual construction and the remainder in the preparation of plans and in the making of surveys. Finally, in 1902, Congress adopted a definite program of road work and appropriated the sum of $250 000 per year for three years.

While the road system laid out by General Chittenden is still in use (1928), it was not constructed to bear the modern vehicular traffic it now sustains. That it could continue to be used by automobiles after the opening of the park to motor traffic in 1915 speaks volumes of praise for his engineering ability, and indeed as an engineer he was ahead of his day and age. Many of the roads laid out by him will continue to be used after they have been widened and surfaced. Only in places will changes have to be made in grade and alignment to bring them up to modern standards. It is doubtful whether extensions of the present road system to regions not now served by roads will be needed.

Extension Throughout National Parks

Federal road construction under the Army Engineer Corps was extended to Crater Lake and Mount Rainier National Parks, but then came to a standstill. When the writer first began, in 1915, to co-ordinate National Park work, he was met with decided views on park road building in the Appropriations Committee of Congress, the members of which did not realize the importance of adequate highways. One Chairman of a House Appropriations Committee suggested that 14-ft. dirt roads, with frequent turnouts for passing vehicles, would serve park needs amply. It was not until members of the Committee had ridden over the old narrow road from El Portal, Calif., into Yosemite Valley, that the first appropriations for rebuilding this road were forthcoming.

During the fiscal years 1917, 1918, and 1919, a total of $160 000 was received for the El Portal Road. From this time until 1924 only small annual appropriations were available for road construction, scattered in the separate park appropriations, while outside the parks, the States with Federal Aid and the Federal Government in the National Forests were building modern approach roads. These roads were bringing increasing numbers of motorists to park boundaries, only to find poor roads to bear the concentrated traffic from the far superior approach roads.

Beginning of Park Road Program

Under these conditions the road situation was becoming very acute. Therefore, in 1924, the Park Service presented to Congress a road program calling for authorization of appropriations of $2 500 000 per year over a three-year period. This bill passed the House and Senate unanimously and became a law. In the first year, however, the National Park Service was permitted to

submit a deficiency appropriation of only $1 000 000, and even this sum was temporarily lost because of the defeat of the deficiency measure by a filibuster in the closing hours of the last session of that Congress. In December, 1924, the new Congress passed the deficiency bill with the item of $1 000 000 for park road work and in the spring of 1925 the first road contracts were let.

The plans had been prepared in 1922, but actual work did not commence until 1925. Meanwhile, road standards had changed rapidly. States which previously had led the Nation in road building were beginning to rebuild their highways to accommodate the motor traffic that had been created with the popularization of the automobile. It is perhaps just as well that funds were delayed, because the park authorities were able to profit by the mistakes of others. Higher standards were adopted for park roads and previous estimates were scrapped.

After a short working period, it became clear that, for the Park Service to handle its road building properly, it would need an engineering force of high caliber. The most competent highway engineers had been developed by the United States Bureau of Public Roads and were either in its employ or with State highway organizations. The U. S. Bureau of Public Roads was then busy in its Federal Aid and other work, getting into mountain road construction comparable to conditions found in the National parks. In the interests of Federal co-operation and co-ordination and the elimination of duplication and waste, an agreement was made between the Secretaries of the Interior and Agriculture whereby the resources of that splendid engineering organization, the Bureau of Public Roads, were made available for the carrying out of the park road program.

It is a splendid working agreement. Since 1925, the Bureau and the Park Service have spent or obligated a total of $9 000 000. They have "taken stock" of the problem and know what they have ahead. Preliminary plans based on reconnaissances have been prepared and presented to the Bureau of the Budget, and to the Appropriations Committee of Congress. The program calls for an ultimate expenditure of $50 000 000, The House of Representatives, in passing the Interior Department Appropriation Bill on January 13, 1928, has made $5 000 000 available for the year 1928-29, and if the appropriations are continued on this basis, the road program will be completed in ten years.

This program does not involve gridironing the parks with roads. It contemplates the reconstruction and surfacing of nearly all old existing roads and the construction of only a few new ones. Nearly all the parks are located in high mountainous regions where road construction is an expensive proposition and where the scenery must be conserved and at all costs left as little scarred as possible. That is the job of the Bureau and the Park Service and that is where the trained Landscape Force of the Park Service is indispensable.

Landscaping of Park Roads

One important requirement is the preservation of park landscapes. In the lower elevations, rigid standards calling for railroad cuts must give way

to rolling grades; straight alignments must be sacrificed for graceful curves where trees or other beauty spots should be saved (Fig. 1). There is no necessity for speedways in the parks. Bridges must fit into the landscape. Where construction must be carried along sheer mountain sides (as in Fig. 2) the excavated material cannot be dumped over to scar the whole terrain. Contracts must provide for end-hauling where necessary and contractors and sub-contractors must be watched to see that they comply with this provision. Rock is being blasted from a cliff along the old Garden Wall Trail at Glacier National Park in Fig. 3. This is typical of some of the difficulties encountered.

The proposed Big Oak Flat Road reconstruction in Yosemite, a contract for the park section of which will be let early in 1929, will be specially guarded in this respect. This road ascends the north wall of the Yosemite Valley. Permitting the excavated material to be dumped off the right of way and to crash down the precipitous granite walls would cause a scar that Nature would require generations to efface. End-hauling on this project will increase the cost, but spread out over a hundred years this will be very little, and compared to the value of the magnificent scenery the cost is infinitesimal.

An example of what it is possible to accomplish along this line can be noted in the work completed in Yellowstone Park in 1927. Years ago, when funds were limited, Army engineers started to build a cut-off between Madison Junction and Old Faithful down the Firehole River. This project is located through a precipitous canyon which affords wonderful views of the rushing river. The work was partly completed, but the excavated rock was tumbled down into the river, making an unnatural ragged bank. Ten years later, when the final mile was completed by park force account, authority was given to preserve the natural beauty of the canyon. A dry rock wall was built up from the river; cut and fill were balanced. The contrast between the old and the new work shows that the cost of $100 000 for this mile of construction was more than justified. On some of the famed roads of Switzerland, it is this attention to landscaping detail—to making the road fit into the picture—that has helped year after year to bring visitors from all parts of the world to enjoy the beauty of the Alps.

Trees must be protected, and side-hill cuts must be made with a consideration as to whether they will become covered with fern, or flower, or shrub. Parapets and rock walls must be designed to harmonize and yet give a feeling of safety in high places.

The Zion Park Road

The Zion-Mt. Carmel Road is one of the most important in the park program. It links the scenic attractions of Southwestern Utah, including Zion National Park, Bryce Canyon, and the North Rim of the Grand Canyon National Park. It reduces the distance between Zion and Bryce from 165 miles to 85 miles and between Zion and the North Rim from 150 miles to 130 miles. It ascends from the floor of Zion Canyon to the East Rim—a rise in elevation of nearly 4 000 ft.—in a distance of 8.75 miles. Contracts for Sections 1

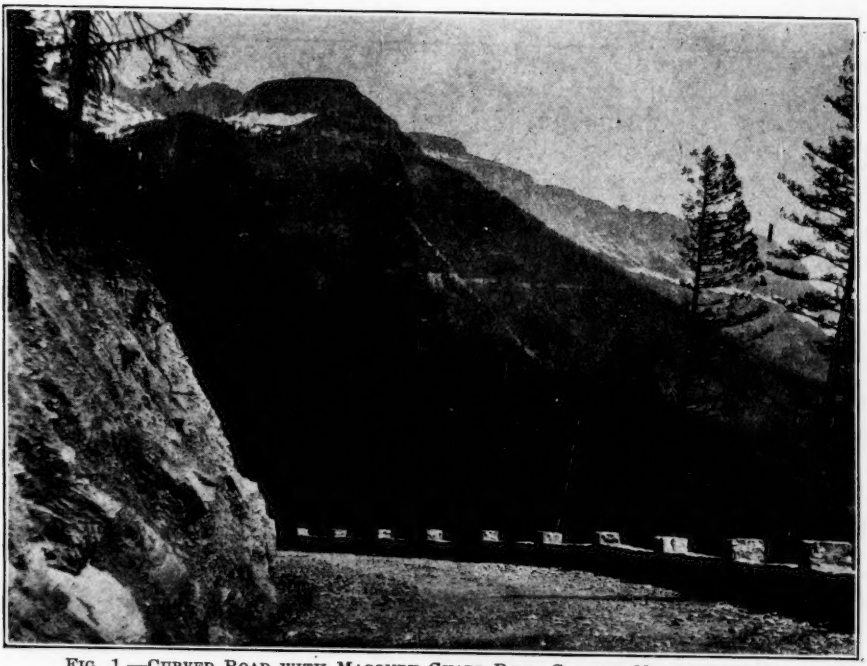

FIG. 1.—CURVED ROAD WITH MASONRY GUARD-RAIL, GLACIER NATIONAL PARK.

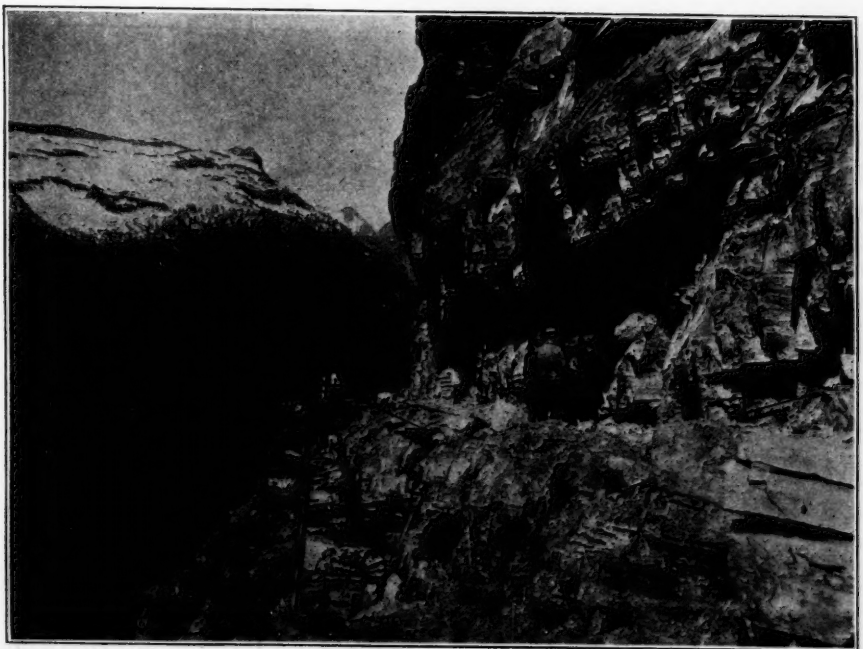

FIG. 2.—CONSTRUCTION WORK ON THE TRANS-MOUNTAIN HIGHWAY, GLACIER NATIONAL PARK.

FIG. 3.—ROCK BLASTING IN GLACIER NATIONAL PARK.

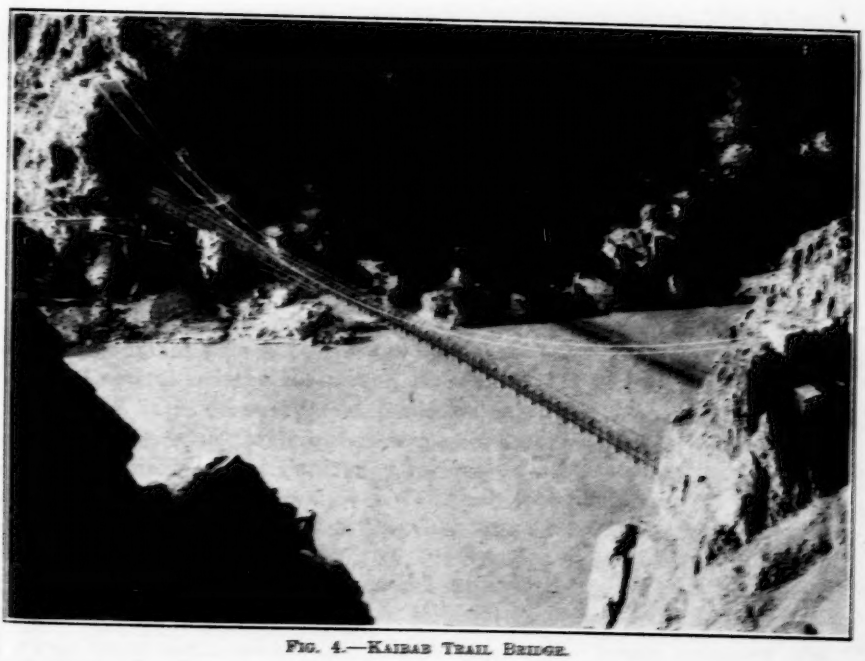

FIG. 4.—KAIBAB TRAIL BRIDGE.

and 2 of this project were let in September, 1927, calling for the construction of 5.02 miles, including 5 582 lin. ft. of tunnel excavation. The cost of this section with an additional small contract will be $800 000. It is estimated that the remainder of the project (3.65 miles) will cost $450 000, or for the total construction, $1 250 000. In addition, the State of Utah is constructing 16 miles of road connecting the east boundary of Zion Park with the Town of Mt. Carmel. It is expected that the park and State road will be completed for travel during the summer of 1929.

Another interesting feature of park road work is found in Mesa Verde National Park, Colorado, where Navajo Indians constitute the bulk of the laboring forces. There is never any difficulty in securing sufficient Navajo help, for when they get word that a construction job is to be started, they drift into the park, build their little "hogans" up against a near-by cliff, and are ready to start work when needed. Some of these same laborers, after the day's work is done, give sections of their "Yeibachai", or medicine dance, at the evening camp fire.

Parking of Automobiles

With the construction of roads comes the ever-increasing problem that all communities to-day are trying to solve—the parking of automobiles. In a restricted area like Yosemite Valley, this has become one of the most important of immediate problems. Mr. Frederick Law Olmsted recently made a preliminary study of parking conditions in Yosemite Valley. As a result he suggests*:

"* * * a principle which ought to be applied generally in the Valley, namely: That wherever there is occasion for the concentrated parking of a considerable number of cars, space should, as far as practicable, be provided for them, having these conditions: (1) Entirely separate from, and screened from, the roads used in moving about the valley; (2) so arranged that no parked car will be blocked in by subsequent arrivals; (3) so interspersed with trees (pre-existing or planted for the purpose), protected from injury (by the use of posts or racks or other guards close to the trunks), that the space and the cars will be largely covered by the foliage and unnoticeable in the plunging views into the valley; and (4) when the limit of such parking is reached, no further parking to be permitted in the vicinity."

Snow Removal

Another pressing problem is connected with the removal of snow from the high mountain passes. Since opening dates for the various parks are announced several months ahead, and railroad tickets to the parks are sold on this basis, it is necessary that roads be cleared of snow sufficiently to permit traffic over the high mountain passes before the opening date. In Rocky Mountain National Park, snow removal is a difficult task, because the Fall River Pass, with an elevation of 11 797 ft. (the highest in the National Park System), must be opened to travel on June 15 of each year, which is the official opening date. In 1927, the 7 miles of road east of the Pass were opened by a steam shovel with a special snow dipper, while 6 miles beyond the west side of the Pass were opened by hand shoveling.

* From unpublished informal memorandum submitted by Mr. Olmsted to National Park Service official.

Sylvan Pass, in the Yellowstone, also presents a difficult snow-removal problem. In 1927, due to the heaviest snowfall in years, more than 15 tons of explosives were used in clearing snow from Sylvan and Dunraven Passes, the Mount Washburn Loop, and the South Entrance Road. Crater Lake also had a serious problem, and the last impassable snow on the rim road was not removed until the middle of August, 1927. Sections of the river road must be rebuilt to avoid these heavy drifts of snow.

Dust Prevention

Until the parks roads are rebuilt, there will be the problem of alleviating the intolerable dust nuisance on some of the existing roads. An innovation in maintenance work in Yellowstone Park in 1927, was the substitution of a light road oil to lay the dust instead of water. This was a much more efficient method, although more costly. The entrance roads and the main loop were oiled for a distance of 126 miles with from $\frac{1}{3}$ to $\frac{1}{2}$ gal. per sq. yd. Old wooden tank trucks were used to haul the oil from cars to the distributor and about twenty wooden storage tanks were set up and used to store the oil. The water sprinkling system is being dismantled as rapidly as possible, as the tanks were an eyesore along the road. Four of the steel ammunition bodies that came with the trucks from World War surplus were covered with steel plates and welded and mounted on trucks and used to haul oil. Nine tank trucks and one distributor truck were used during June, July, and part of August, in transporting and spreading approximately 300 000 gal. of road oil.

Sanitation

One of the outstanding perplexities has been the providing of the necessary sanitary arrangements and safeguards for the traveling public. In the early days of Park Service history, when there were comparatively few visitors, common earth toilets and the burning of garbage in open pits—after first allowing the bears to work over it as an attraction to the tourist—were found to be sufficient. In the more modern days, however, this problem has the same phases as in large cities. Toilet facilities are being gradually changed to the most modern of city systems and garbage is being disposed of by especially designed incinerators. In conjunction with the garbage disposal, there are can-mashers to reduce the refuse cans to small bundles of unrecognizable metal, which are easily disposed of in such small compact masses.

The water systems are modern in every way. Originating in undefiled mountain streams and springs, the water is safeguarded by frequent analyses, and every precaution is taken to keep it free from contamination until it reaches the consumer. Inspections of the culinary arrangements in all hotels, camps, and concessions where public food is handled and sold are made regularly. In Grand Canyon National Park, where the water supply is a serious problem, and water has to be hauled for many miles in tank cars, a system has been perfected which purifies the waste water to the extent that it may be safely used over and over for flushing toilets, washing automobiles, and for many other non-domestic purposes. This effects a saving of thousands of dollars each year in haulage costs alone.

In Mesa Verde National Park where there is no live water during the summer the Park Service authorities have had to resort to the development of the water supply by catchment and storage. One unit has been constructed which provides for a corrugated, galvanized-iron catchment area, 1 acre in extent, with two steel frost-proof storage tanks, each with a capacity of 125 000 gal. The catchment area gathers, by means of a flume, the snow and rain falling thereon and conducts them through a rapid sand filter to the steel storage tanks. These steel tanks have not proved entirely satisfactory because when warmer weather prevails the water has a decided flatness and taint, possibly due to pollen from pinon trees. Funds have been included in the new Appropriation Bill for the construction of a second unit, in which concrete storage tanks will be substituted for the steel tanks. Plans for this work are now (1928) being drawn.

All this sanitary work has been accomplished by the able assistance and splendid co-operation of the expert sanitary engineers of the United States Public Health Service.

Power, Telephone, and Telegraph

In many of the National Parks there are hydro-electric systems which furnish light, power, and heat for administrative purposes within the boundaries. In numerous instances where it would be difficult, if not impossible, to obtain electricity from other sources, the surplus is furnished to the operators of the public utilities at reasonable rates. Most of the parks are abundantly supplied with possibilities for development along these lines, and local systems to supply the needs of a park are being augmented from time to time as funds become available. These problems are handled individually and frequently are difficult to solve since neither water-falls nor cascades can be used, and all installations must be made so as to mar the scenery as little as possible.

In order to provide adequate long-distance telephone service in Yellowstone, the American Telephone and Telegraph Company, using the Hotel Company and National Park Service pole lines, strung a two-wire, No. 128, copper, metallic circuit from Mammoth Hot Springs to Old Faithful and West Yellowstone, and another circuit from Mammoth Hot Springs to Yellowstone Lake *via* the Grand Canyon, and new magneto switchboards were placed at Mammoth Hot Springs, Old Faithful, the Grand Canyon, and Yellowstone Lake. These new copper circuits are built through to Helena, Mont., and give the park high-class, exclusive service. The new system when completed will cost about $150 000.

In the Carlsbad Cave National Monument, New Mexico, there is an entirely different electrical lighting problem. This is the largest and probably the most beautifully decorated cave known in the world. The trip through the cave requires about five hours and proper lighting is of paramount importance. Congress is granting funds for this work and members of the Appropriations Committee who have visited the Caverns have taken a great interest in the problem. They have suggested that Park officials consult with some of the best known electrical and stage lighting experts, with a view to

developing a system so that the lights will come on slowly until full illumination is obtained and then gradually die down to add to the impressiveness of the scene.

Trail Construction

Great wilderness areas must be retained in all the parks to be entered only by trail. These are for the horseback rider and hiker, as well as the administrative forces on game and fire patrol. Trail-building plans must go hand in hand with the road-building program. Some trail construction that is not equalled anywhere else in the world has already been completed. The trail across the Grand Canyon, according to travelers familiar with all parts of the world, is the best construction to be found. A view of Kaibab Trail Bridge is shown in Fig. 4. The lower cable is provided to support the suspension bridge against wind.

Diverse Engineering Problems

This paper illustrates some of the diverse engineering problems which confront the National Park Service. They involve the expert services of the highway engineer, the landscape engineer, the sanitary engineer, the electrical engineer, and the mechanical engineer. A point has now been reached in park development where the same problems are encountered as in town planning.

To a great extent, visitors in the National Parks are gregarious and desire to herd together in the large public camp grounds. Streets must be laid out, sanitary conveniences located, water lines installed, and community buildings erected, where visitors may gather during inclement weather and in the evenings. Incidentally, these community buildings have become centers for educational work. With the increased crowds comes the necessity for hospitalization. In a few of the parks there are already some hospital facilities and these are now being extended into other parks.

Conclusion

The writer would also like to mention wild life preservation, and methods of combating insect infestations by means of power sprayers and in other ways, because although park work is primarily based on preserving the natural features of these reservations while at the time developing them for tourist use, engineering along some lines is a big factor in nearly every phase of the Park Service activities. Park officials could not continue to serve the public were it not for the engineers.

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FLOOD CONTROL WITH SPECIAL REFERENCE TO THE MISSISSIPPI RIVER

A SYMPOSIUM

Discussion *

By Messrs. W. E. Elam, R. W. Davenport, and E. W. Lane.

W. E. Elam,† M. Am. Soc. C. E. (by letter).‡—That section of the Mississippi River lying between Arkansas City, Ark., and Greenville, Miss., known as the Greenville Bends, is, in many respects, one of the most interesting on the river.§ At this point a series of five great bends are lying so close together that 45 miles of the river are compressed into a rectangle of approximately 9 by 10 miles (see Fig. 57). Two points, 40 miles apart by river, are only 10 miles apart in a straight line. Local tradition tells of the Indian, who, having to travel from Greenville to Arkansas City, floated down stream 5 miles, cordelled (that is, pulled his boat) across Leland Neck; floated down stream 4 miles; cordelled across Tarpley Neck; floated down stream 4 miles; cordelled across Linwood Neck; floated down stream 3 miles; cordelled across Ashbrook Neck; and by this process was 30 miles up stream from his starting point without having to row up stream at all. Instead, he had floated down stream about 16 miles.

The Mississippi River Commission estimates the possible range at the upper end of the Greenville Bends to be 78.1 ft. Considerable revetment, as well as two long spurs built to prevent cut-offs, are found in this reach. Here, the greatest change in flow conditions has been caused by the construction of levees, and a large percentage of the discharge flows across necks during extreme high stages of the river. The upper section is one of the wide sections

* Discussion of the Symposium on Flood Control with Special Reference to the Mississippi River, continued from August, 1928, *Proceedings*.

† Asst. Engr., Mississippi Levee Board, Greenville, Miss.

‡ Received by the Secretary, May 29, 1928.

§ *Engineering News-Record*, June 28, 1928, p. 996.

and the lower end, at Warfield, Miss., is one of the much discussed "bottle-necks" that does not entirely bear out popular ideas.

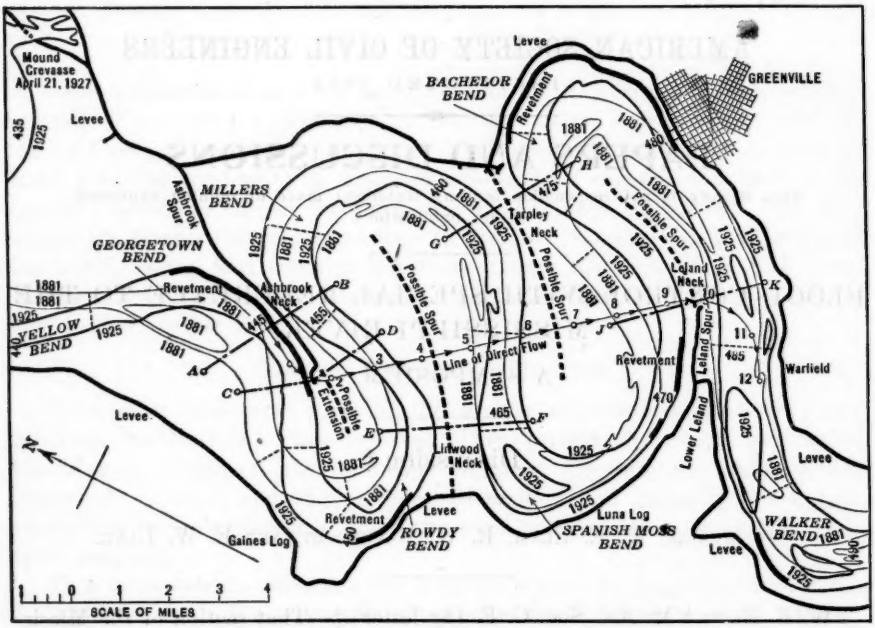

FIG. 57.—THE GREENVILLE BENDS, MISSISSIPPI RIVER.

A detailed study of the hydraulics of this reach would do much to clarify flood control problems. It is an ideal hydraulic laboratory and a little more complete data on bank-full and lower waters would furnish a complete study of the slope problem that must be solved to get and maintain an adequate channel. Enough information to determine the normal slope is essential, but even this will be of little value unless high and low-water channel lengths and locations are made coincident. Then, determination of the proper length of channel to lower the high-water levels will be possible. It must be recognized that this discussion is a study using "incidental data" and the results can only be accepted as such. The maps and other data used, are largely taken from published records of the Mississippi River Commission and are known to be very accurate; but some vital data are interpolated from known data that may not be close enough for final conclusions.

Physical Features.—Under low and moderately high-water conditions this part of the river is a simple channel, 56.74 miles long, from a point just below Arkansas City to Warfield Point about 5 miles below Greenville. When the water level gets above the natural surface of the ground at the neck sections, each neck becomes a weir, by-passing varying volumes of water to the bend below. The ends of these points are much higher than the neck sections and are constantly being built higher with deposit left by each extreme high water. On most, and probably all, of these points are small areas of land that build

up almost as fast as the water rises. With a fall of less than 1 ft. from a maximum stage, land begins to appear on these points. The necks show some tendency to build up, but owing to the depth and velocity of the water, the rate of deposit is not nearly so rapid.

The gauge relation between the Arkansas City and Greenville gauges has changed materially since 1881. Fig. 58 was constructed by plotting the differences in gauge readings for waters cresting between 10 and 30 ft. on the Arkansas City gauge. Two periods were selected, 1882 to 1887, inclusive, and 1922 to 1926, inclusive. The differences are plotted as plus quantities, using Arkansas City as a base. The Arkansas City gauge readings have probably been changing more than the Greenville readings, as there has been less change in channel length and flow conditions immediately below Greenville than between Arkansas City and Greenville. The curves could be drawn by eye through these points close enough for the purpose and show that for waters cresting in the low-water channel, and not flowing across points, the Arkansas City gauge averaged about 3¼ ft. higher between 1922 and 1926 than it did from 1882 to 1887. This is an average increase of about 1 in. per year for the period. Discharge observations are not readily available to compare the discharges over these gauge readings during these periods. Only two stations on the river, showing a maximum discharge in 1927, have been given by the Mississippi River Commission.* These are at Chester, Ill., and Carrolton (New Orleans), La., both far removed from this reach. This change of gauge relation is not in the right direction to indicate increased carrying capacity of the channel and must have some cause in the low-water channel because the writer has not considered any other water in determining the gauge relations. Two main causes that could produce this result are: (1) Lengthening of the channel; and (2) deterioration in the discharge capacity of the channel.

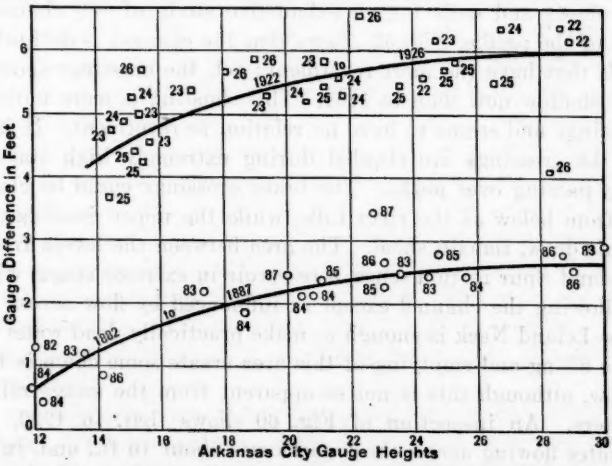

FIG. 58.—GAUGE DIFFERENCE BETWEEN ARKANSAS CITY AND GREENVILLE.

In 1881 and 1925, the length of the channel differs slightly from that given by the Commission. No very great refinement was attempted, but the dis-

* Special Rept., Mississippi River Comm., November 28, 1927, Special Table No. 5.

tances were measured on the map as nearly along the line of the center of gravities of the sections as could be estimated by the eye. The length was estimated to be 48.34 miles in 1881 and 56.74 miles in 1925. The average slope from 1882 to 1887 was 0.218 ft. to the mile, and from 1922 to 1926, it was 0.247 ft. to the mile. This is a considerable increase of slope (in a longer channel) in view of the fact that two of these bends are practically completely revetted. This indicates that revetment alone cannot be depended on

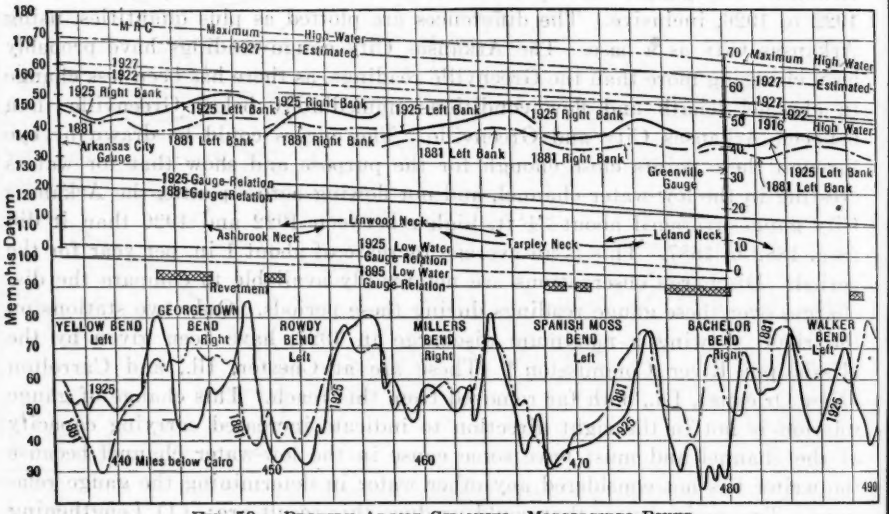

FIG. 59.—PROFILE ALONG CHANNEL, MISSISSIPPI RIVER.

to flatten slopes and calls for an exhaustive study of the channel-way. An inspection of the profile, Fig. 59, shows that the channel is decidedly deeper in those bends that have the most revetment; yet, the crossings show a tendency to be more shallow now than in 1881. This shoaling is more noticeable in the upper crossings and seems to have no relation to revetment. It is more probable that the crossings are shoaled during extremely high stages when the water is by-passing over necks. The lower crossings could be cleaned out by the draw from below as the river falls, while the upper crossings, beyond the effect of this draw, remain shoal. The area between the levees from Ashbrook Spur to Leland Spur is, in a sense, a reservoir in extreme stages with the main current following the channel except as influenced by flow across necks. The draw across Leland Neck is enough to make practically dead water in Bachelor Bend. The filling and emptying of this area create some changes from normal channel flow, although this is not so apparent from the gauge relation of the higher waters. An inspection of Fig. 60 shows that, in 1922, the average depth of water flowing across these necks was about 10 ft., and, in 1927, about 13 ft. The timber and undergrowth serve to check the velocity and maintain the slope at present. Whether this will continue at higher stages cannot be foretold. Shoaling of the channel in the bend also serves as a balancing influence and helps to maintain the slope.

The break in the slope of the low waters appears to be very much changed since 1881. At that time the upper part of this reach had a slightly steeper grade, while now the lower section is the steeper and there is a decided hump in the slope through Miller's Bend which is behind Ashbrook Spur and is affected by the by-passing over Linwood and Tarpley Necks. This is shown on Fig. 59. The break in the slope in Bachelor Bend opposite Leland Point shows the presence of a constricted channel during high stages at this point

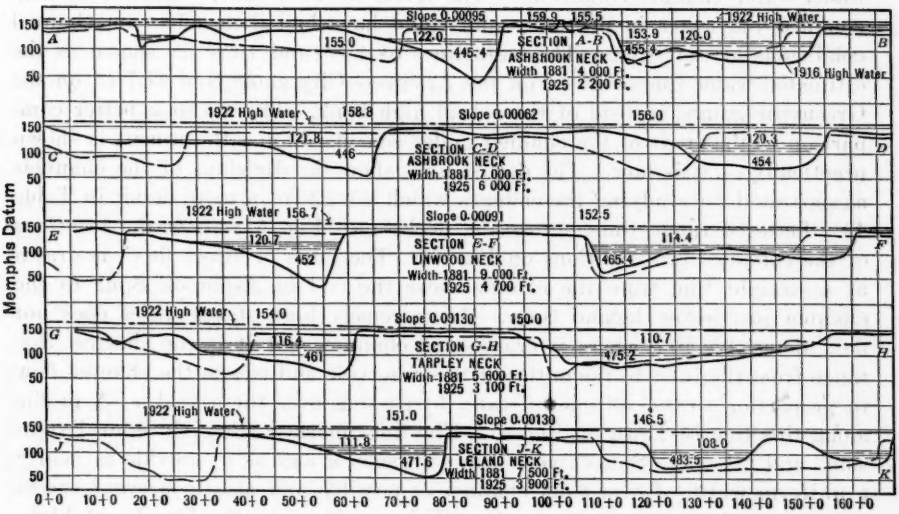

FIG. 60.—SECTION ACROSS NECKS, MISSISSIPPI RIVER.

where it is 6 miles between levees and also 9 miles above the "bottle-neck" at Warfield, where the levees are only 6 600 ft. apart. In extreme stages so much water is passed over Leland Neck that there is practically no current in Bachelor Bend and the constricted channel is probably due to deposit dropped when the water is checked. The heavier materials would not be carried over the neck and would stay in the channel until dropped by the diminished current. It is also interesting to note that the channel is silting up at this "bottle-neck" and that the water lines show that there is no constriction at this point in either low or high water. When the water gets past Leland Neck it seems to have a free outlet. The only explanation for this is that the swift current that prevails here during high stages makes up for the lack of area, but this does not explain why the area is getting smaller. If it was known at what stages and under what conditions this deposit took place, some explanation could be given.

In order to determine the changes that have taken place in this reach, the Mississippi River Commission maps of 1881 and 1925 were reduced to a scale of 2 in. to the mile for working sheets. In the channel 10-ft. contours were drawn from soundings given on the maps. The zero contour on both maps is the estimated water surface of a crest of 20 ft. at Arkansas City passing to a crest of 17.7 ft. at Greenville, which was the gauge relation in 1881. It

must be recognized that this discussion is a study of incidental data. The maps are known to be accurate, but this is a use not contemplated when they were made; also, the exact determination of this water slope is impossible now. The data available are thought to be close and the line to be within a very few tenths of the actual slope.

Fig. 57 is a combination of the two working sheets, except that only 20-ft. contours are shown in the 1925 channel in order to give a better idea of the under-water channel conditions. The levees of 1881 can be ignored as they confined the water ineffectually and could have had little effect on channel conditions at that time. The bank lines of 1881 and 1925 are shown as the estimated water line at 20 ft. on the Arkansas City gauge and 17.7 ft. on the Greenville gauge, instead of the actual high bank. This is for a better comparison of that part of the channel under consideration. Revetment is shown practically as it is now. The dotted lines show the divisions of the channels as separated for studying the changes which are given in more detail in Table 42. Lettered range lines across the necks (see Fig. 57) show the locations of the compiled cross-sections on Fig. 60. The "line of direct flow" is drawn as a straight line from the channel near the end of Ashbrook Spur to the channel just below Leland Spur. At extremely high stages water does not flow along this line where it crosses the channel; but it is the shortest distance from the inlet to the outlet of this reservoir and effects the channel flow in proportion to the volume of water by-passing over these necks. A profile along this line is shown on Fig. 61. The lines marked "Possible Spur Extension" and "Possible Spurs" were drawn in such a way as to provide as nearly a uniform width of over-bank channel as possible and also to prevent excess by-passing of water over the necks. This would make the lengths of high-water travel very nearly the same as the low-water travel and would probably cause the channel to enlarge and perhaps scour out the shoaled crossings. To do this without reducing the length of the channel enough to compensate for the water that now by-passes over these necks, would probably raise the Arkansas City gauge to greater relative heights as compared with the Greenville gauge. Assuming that the 1881 channel was a natural channel, that length might be a very good guess. It is possible, though, that it might be less and perhaps cause more lowering of the Arkansas City gauge. This is a problem because, when the channel is enlarged, the slope may become flatter. With the by-passing and channel disturbances that now exist, it is not possible to state what the natural slope would be or even what it is now in this reach. From the profiles along the channel this appears to be a very flat section of the river when, in fact, it might be the reverse. There is also some doubt as to what the Arkansas City-Greenville gauge relation would be with a maximum or a 1927 estimated water confined between levees and greatly increasing the flow across these points and further disturbing the slope. The probability is that this break in the slope in Bachelor Bend would be accentuated and the fall across Leland Neck would be greatly increased. The Arkansas City gauge could hardly be reduced because it is just below the foot of a larger reservoir section very similar to this, except that the Arkansas and White Rivers empty into it.

Fig. 59 is based on the 1925 distances, in order to bring all possible points in common and compare changes. The depths of water, taken from soundings, are the greatest in each line of soundings. At crossings, one sounding may be on one side of the river and the next sounding on the opposite side, with no regard to alignment. This method is thought to show more nearly the actual hydraulic conditions than that of following any alignment. Revetment is indicated as well as the approximate surface elevations along the neck sections immediately below each bend. High-water lines are shown as nearly as it is possible to estimate them from elevations along the levees on both sides of the river. The gauge relation in 1881 and 1925 is shown distributed. This distribution is based on only one water in each instance and then is adjusted to average gauge relations.

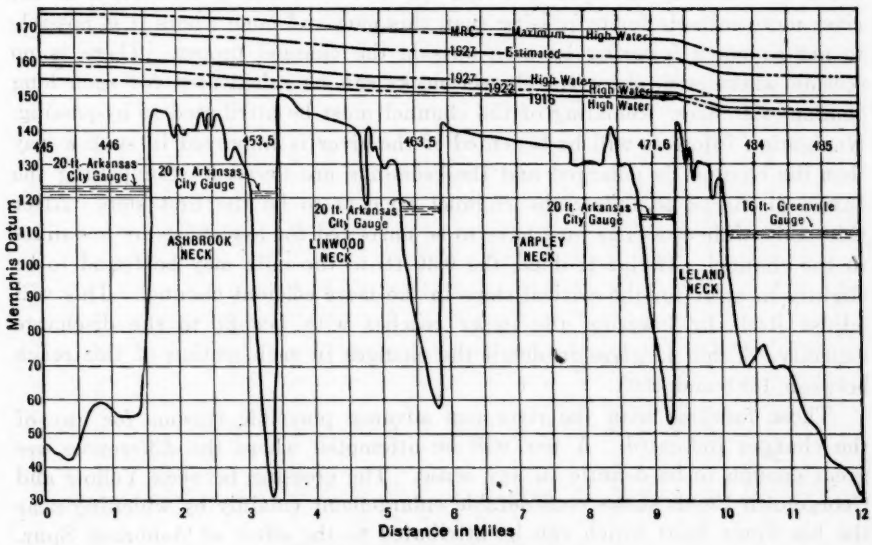

FIG. 61.—DIRECT-FLOW PROFILE.

The Ashbrook Spur was completed after the high water of 1916, and seems to have had some effect on the water lines, although not as much as the general public thinks. The 1916 water shows a depression at about Mile 450 (not shown in later waters) that is probably due to the local effect of the flow across Ashbrook Neck. The Arkansas City-Greenville gauge relation was 5.65 on that crest and 6.03 in 1922. This small increase could be attributed to the lengthened travel of the water in going around the spur instead of across the narrow neck, but lengthening of the channel is the more reasonable cause. During the 1922 high water, rapid currents were very noticeable near the outer end of Ashbrook Point both in the channel and across the point. This must have enlarged that channel to some extent. Scaling this slope on Fig. 59 shows it to have been about 0.17 ft. to the mile in 1916, 0.33 ft. in 1922, and 0.30 ft. in 1927. This is a closer agreement with anticipated results than was hoped for with the data used, and it confirms the assumption that

the channel was first clogged up and then scoured out in 1922, restoring the normal slope nearer the critical point through an enlarged channel. This indicates that 0.30 ft. to the mile is approximately the critical slope for this reach of the river. Using this as a basis, the 35 miles of river that existed in 1881 will give a difference of 10.5 ft. in the elevation of the water at these points, which corresponds exactly with the gauge relation curve. This was in a channel that was little affected by by-passing. The distance now is 43.5 miles and calculating the theoretical drop in the same way gives a difference of 13.05 ft. against an actual difference in 1922 of 13.86 ft. This indicates that flow across points helps little and may be a detriment. It also gives the hydrologist something to think about when he is hoping to get relief from high floods by widening the space between the levees. There is no section of the river more suitable for by-passing than this part and none where it is possible to get as much lowering by area outside the channel proper. There is no section where such short travel over necks can be substituted for such long channel distances. Shoaling of the channel must be attributed to by-passing. Navigation interests will be benefited if the river is improved in such a way that the channel is enlarged and the crossings are lowered. Compelling the entire discharge to follow the channel appears to be the first step. After this, some wide crossings may have to be narrowed for low stages by low dikes in the channel. If this is done, the 0.30 ft. to the mile may be found to be slightly in error for the critical slope in the more efficient channel. This will adjust itself by lowering the upper reaches with benefit to the discharge capacity. Table 42 gives in detail the changes in each section of this reach between 1881 and 1925.

Those familiar with the river can advance plausible reasons for any of the changes indicated. A few will be attempted where the differences are great enough to be definite in any sense. The crossing between Yellow and Georgetown Bends shows considerable enlargement (mainly by widening near the low-water line) which can be attributed to the effect of Ashbrook Spur. The Georgetown-Rowdy Bend Crossing seems to have lost area, and this might be due to material that came from above and to the fact that the force of the water was not enough to clean it out. Probably Ashbrook Spur is too short to create the current necessary to do this. Georgetown and Bachelor Bends, both almost completely revetted, show deepening and loss of total area but a gain in under-water area. This shows the good effect of revetment and the evil effect of allowing water to by-pass the channel when the current is best able to carry this material away. The Miller-Spanish Moss Crossing shows a loss of area and depth and an increase of width, probably due to island growth, aided by by-passing. In Table 42 the columns showing channel width are significant. With two exceptions (Rowdy and Miller's) the bends show a decided narrowing and deepening. The loss in area is mainly between low water and 20 ft. on the Arkansas City gauge, while on the average below the low-water line the area shows a gain. This indicates that revetment is mainly effective during low water. It is a little too much to expect to get this effect in high water when the force of the water is expended over the necks.

TABLE 42.—CHANNEL DATA AND VARIATIONS BETWEEN 1881 AND 1925, ARKANSAS CITY, ARK., TO GREENVILLE, MISS.

Reach or section of river.	Length, in Miles.		At 20 Feet on Arkansas City Gauge.						At 0 Feet on Arkansas City Gauge.						Remarks.
			Average cross-section, in square feet.		Average width, in feet.		Minimum width, in feet.		Average cross-section, in square feet.		Average width, in feet.		Minimum width, in feet.		
	1881	1925	1881	1925	1881	1925	1881	1925	1881	1925	1881	1925	1881	1925	
Yellow Bend	1.70	1.83	113 500	107 500	2 410	2 360	2 100	2 200	69 000	65 200	2 140	1 985	2 000	1 950	Little revetment; shoaled.
Crossing	2.00	2.15	103 000	110 000	3 300	3 330	2 800	2 500	47 300	48 300	2 280	2 780	2 000	2 500	Depth decreased.
Georgetown Bend	3.95	4.48	106 200	101 000	3 760	2 960	3 000	2 300	41 800	50 300	2 550	1 840	1 800	1 250	4 miles of revetment; deepened.
Crossing	1.90	2.00	132 700	115 300	3 340	4 090	2 750	3 400	74 800	42 000	2 315	3 710	1 900	1 700	Depth decreased.
Rowdy Bend	4.15	6.17	116 200	118 800	2 570	2 600	1 800	1 900	65 500	73 000	1 915	2 060	1 700	1 700	1 mile + revetment; deepened.
Crossing	2.00	2.10	101 500	112 300	3 780	4 230	3 200	3 500	34 800	38 900	2 870	3 020	2 600	3 250	Depth decreased.
Miller's Bend	6.20	7.77	105 000	100 800	3 260	3 440	2 500	2 220	52 500	46 600	2 140	2 450	1 700	1 100	No revetment; little change in depth.
Crossing	2.00	2.00	119 500	116 500	3 600	3 980	3 000	3 500	51 800	45 000	2 700	2 940	1 800	2 800	Depth decreased.
Spanish Moss Bend	8.10	10.30	109 300	94 000	3 190	2 990	2 100	1 800	56 500	57 700	2 100	2 025	1 700	1 600	2 miles + revetment; deepened.
Crossing	2.00	2.00	135 000	93 000	3 670	4 050	3 000	2 700	37 000	43 400	2 700	3 020	2 300	2 300	No change.
Bachelor Bend	5.35	6.18	111 000	108 000	3 670	2 660	2 800	1 700	57 700	61 400	2 230	2 010	1 700	1 300	5-mile revetment; deepened.
Crossing U½	2.93	2.85	123 000	143 500	4 720	4 870	3 500	3 900	39 800	58 700	3 100	3 480	2 100	3 700	Above Leland Spur; deepened.
Crossing L½	3.16	2.94	131 000	112 000	4 670	3 920	4 400	1 900	45 900	56 300	3 100	2 180	2 100	1 600	Below Leland Spur; deepened.
Walker Bend	2.90	3.97	135 500	132 500	5 470	5 220	3 200	4 500	44 000	49 000	3 640	3 100	2 800	2 200	Much improved; deeper.
Totals or averages..	48.34	56.74	113 200	109 000	3 620	3 420	.....	.....	52 200	54 700	2 530	2 430	.....	.....	.....

The writer defines critical velocity as that at which the material forming the bed and banks of the river is on the point of being moved by the force of the current. This velocity depends somewhat on the material and its resistance against disturbances. Critical slope is the slope or fall per mile necessary to create the critical velocity in the channel under discussion. The critical slope varies with every change of channel shape and channel material. The discharge channel, its size, and shape, depend on the critical slope. If the slope is less than the critical slope, the discharge channel will decrease in area and build up the upper reaches and the slope; if more, the channel will scour and restore the critical slope. The channel can scour either wider or deeper. If it widens, the critical slope becomes steeper; if it deepens the channel, the critical slope flattens. For this reason the river will have to be regulated to a very close margin in order ever to be able to tell exactly what results will follow these changes. While this is being determined the river can be regulated for all practical purposes and lowered gradually to obtain the required discharge channel. One problem to face when this is started will be to keep the sediment in motion, and this can probably be done by shunting most of it into old sections of the river that are to be abandoned, regulating this by a close determination of the slope. To get a channel for the Mississippi River large enough to carry a maximum flood, conditions will have to be created that will set up velocities in excess of the local critical velocities. Adjustment of length and alignment is the simplest method to get this condition. The entire flow must first be concentrated on the desired channel by properly located levees or spurs and further undesired bank caving prevented by revetment. The present concrete revetment used in the Third District, Mississippi River Commission, has about reached the stage where it can be depended on to hold almost any bank.

The Mississippi River has banks in the middle reaches that appear almost fluid at times. The hydraulic adjustments look almost hopeless when changing flow conditions create trouble at unexpected places; but the concentration of the flow along the same location for both low and high-water conditions will, no doubt, remedy this to a great extent.

The reach described is only one of many in the river from Cairo, Ill., to Baton Rouge, La. Beginning 10 miles above Arkansas City is a wide reach about 24 miles long, with an average width of 11 miles, that is even more complicated in its hydraulics. It has the Arkansas and White Rivers emptying into the upper end of it, and the back-water area of these two rivers adds complications to the problem. This area may be one of the places that cause the great range between high and low waters at both the White River and Arkansas City gauges. However, it is so disposed that, by constructing a spur about 17 miles southward from the Laconia Circle Levee, the back-water levels would be materially reduced and would give a more normal slope in the Mississippi River from White River, Ark., to Arkansas City.

All these considerations, then, support the following conclusions:

1.—Changes in gauge relations are due primarily to changes in channel length.

2.—Flow across points, or outside the channel proper, has little effect on slope, unless cut-off is imminent; then the slope in bend is flattened locally, thereby hastening channel deterioration and the cut-off.

3.—Flow across points tends to steepen the general channel slope and raises the upper gauges by checking the water in the bend and causing deposit which diminishes the channel efficiency.

4.—Channel elevations can be controlled to some extent by regulating the distance to tide-water.

5.—Channel capacity can be increased by making high and low-water channels coincident.

6.—Cut-offs require several high-water periods to develop and are seldom, if ever, accomplished suddenly.

7.—A study of channel changes throughout all the cycles of an actual cut-off is essential. Then, knowledge of facts will take the place of opinions.

R. W. DAVENPORT,* M. AM. SOC. C. E. (by letter).†—The studies‡ of Messrs. Woodward and Nagler show that apparently there has been no appreciable change in the flood run-off from the Des Moines and Iowa Rivers, caused by extensive development affecting one-third or more of the parts of the drainage areas considered. The authors conclude that agricultural drainage has had a negligible effect on the magnitude of either the total flow or the maximum discharge of the floods of the Mississippi River, since less than 5% of the water-shed has witnessed agricultural drainage operations.

Agricultural drainage undertakes to facilitate the escape of storm waters from agricultural lands and, consequently, when established on a large scale the possibility is suggested that its influence will be reflected by some modification in the regimen of stream flow from that existing in a state of Nature. The conclusion must be accepted, apparently, that particles of water falling on a drained area will pass through a cycle of behavior different from that which would have occurred before drainage. The determination by inductive processes of the net effect of the modified behavior on the resulting stream flow seems quite complex. Moreover, the characteristics of stream flow with respect to quantity and occurrence depend on numerous factors, and the effect of a change in a single factor, unless it is of predominating importance, may be obscured or practically obliterated by variations in the behavior of other factors.

If one can detect no appreciable effect of drainage works on the flood discharges of the Des Moines and Iowa Rivers, it may mean that the effect is relatively so small, in comparison with the flood discharges, that it is obscured by the variations of factors which are active in the production of floods. If one could determine what the net effect of drainage may be at lower stages where it can perhaps be more easily detected, it might throw some light on the nature of the effect at high stages.

A comparison of the characteristics of stream flow with respect to frequency of occurrence by use of the duration table or curve affords an excellent

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† Received by the Secretary, September 26, 1928.

‡ *Proceedings*, Am. Soc. C. E., January, 1928, Papers and Discussions, p. 165.

means of studying changes in the regimen of flow in a given stream by artificial causes. It occurred to the writer that such a comparison for the Des Moines and Iowa Rivers might be illuminating in this instance. Fig. 62 shows the results obtained for Des Moines River at Keosauqua and for Iowa River at Iowa City. The comparison is made in each case between the 3-year period, June, 1903, to May, 1906, and the 6-year period, October, 1917, to September, 1923. The investigation did not include the Des Moines River at Fort Dodge and Des Moines, because the records were not continuous through these periods. It is recognized that the periods studied are not long enough to show the frequency distribution with close accuracy, but it was thought that they might show evidence of any outstanding changes.

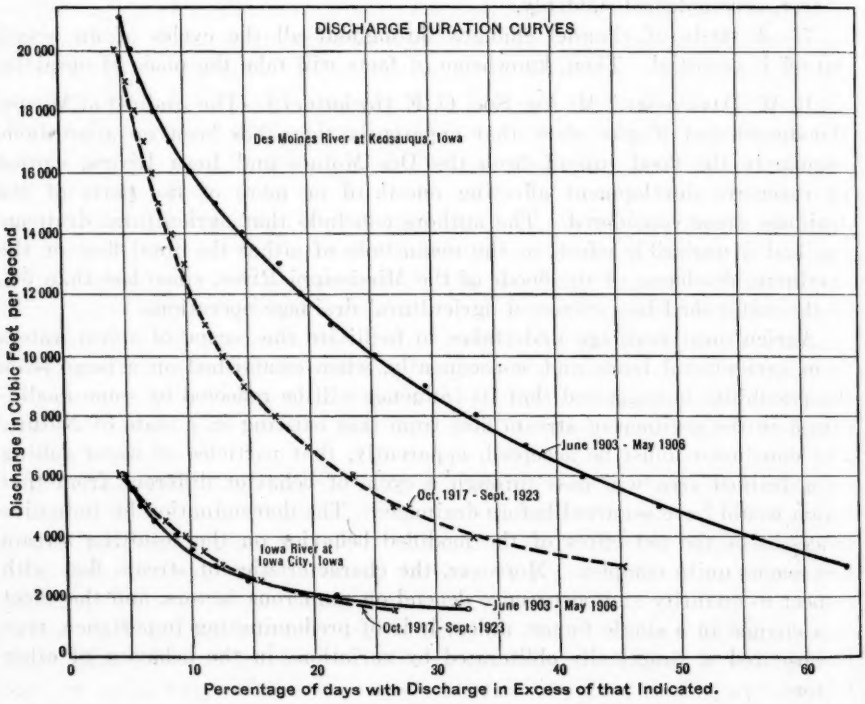

FIG. 62.

Because of inaccuracies involved in estimates of flow in times of ice cover, which, however, generally affect only the lower discharges, no attempt is made to define the duration curve below 3 000 cu. ft. per sec. for the Des Moines River, or below 1 500 cu. ft. per sec. for the Iowa River. Data are not shown for the highest discharges, 5% of the time being taken as defining the upper limit.

The curves for the Iowa River within the limits shown appear to be rather similar for the two periods. There seems to be a tendency for more frequent occurrence of lower discharges in the later period, 1 500 cu. ft. per sec. having been exceeded 33% of the time in the first period and 27% in the second.

It may be that the records are not long enough to make this difference of special significance. If it is significant it is consistent with the deduction that the effect of drainage is to reduce effective ground-water storage, thereby taking away in part the reservoir available for maintaining low-water flow. It would, of course, be a corollary to this that there must be a corresponding increase in the higher discharges. However, such increase need not have affected the highest discharges. In fact, it seems possible that in a flat country typical of those where drainage is practiced, a condition might exist comparable to that of a lake. If the ground and surface storage on the drainage area, like the storage on the surface of the lake, were utilized to high capacity, the escape of water from the storage on the drained area might be determined to a predominating extent by physical features largely or entirely unaffected by drainage works, in a similar way that the escape from the lake at any given stage is controlled by the characteristics of the outlet and is unaffected by artificial changes in the bed or shore of the lake at a distance from the outlet. Under the assumed condition, facilitating the escape of water from the drained area would become proportionally more effective as the stage of water fell and artificial drainage channels became relatively more influential in the discharge of water.

The results for Des Moines River show a difference in the characteristics of the occurrence of stream flow between the earlier and later periods, which is so great that it is not easy to reconcile it with the facts in an adequate way. The data indicate that the mean flow for the latter period is materially less than that for the former. It appears from superficial examination of precipitation records that there was apparently not sufficient variation between the two periods in regard to this factor to explain any material difference. This is supported by the fact that on the neighboring drainage area of the Iowa River there was no similar wide difference in quantity of run-off between the same two periods. Examination of the data on which the estimates of discharge were based, indicates no probability of any misinterpretation which could adequately account for so wide a variation. The writer's experience leads him to suspect that the apparent difference is probably greater than would be expected unless there had been a change in some important factor entering into the determination of run-off. However, he is unable to reconcile satisfactorily the extent and character of the apparent change in regimen with any probable effect of agricultural drainage.

Although failure to explain this difference may seem to make its consideration of little value to this discussion, it is presented as possibly having some bearing on the validity of conclusions based on the comparison of these records and with the hope that the authors will state from the standpoint of their intimate knowledge what they believe is the correct explanation of the matter.

E. W. LANE,* M. AM. SOC. C. E. (by letter).†—Psychological conditions are often major items in flood control. Rarely, if ever, is a locality given adequate protection against floods until after a catastrophe has occurred with damages greatly exceeding the cost of suitable flood-control works. The City

* Associate Engr., U. S. Engr. Office, Baltimore, Md.
† Received by the Secretary, September 27, 1928.

of New Orleans, La., is an extreme case of this condition. In spite of the frequently repeated example of the need of adequate protection in years past, culminating in the damage of several million dollars resulting from the artificial crevasse at Caernarvan during the 1927 flood, the danger from flood is as great as, or greater, in New Orleans than in any city of which the writer has knowledge. Such an obvious condition has not escaped the attention of some of the local engineers, but a frank statement of the situation is frowned upon by those who fear that it may frighten away business, or increase the apprehension of the citizens.

Some of the protection work has been excellently done. Levees with 50-ft. crown, 1 on 4 river slopes, and 1 on 10 land side slopes inspire confidence. Even though the free-board is slight, there is ample opportunity for emergency topping which will hold stages higher than the poorer levees up stream. However, a chain is no stronger than its weakest link, and in this same main river levee are sections no larger than the old Mississippi River Commission standard, which the 1927 flood demonstrated to be inadequate even for the protection of agricultural land.

The greatest danger to New Orleans in the recent flood was not these main river levees, however, but in its second line of defense. Up stream from the city extends one of the weakest stretches of levee along the entire river. A breach there might flank the main river levees and flood a large part of the city. To guard against this contingency, a protection levee was built from the main river line to Lake Pontchartrain, connecting with the lake levees there. This is little more than a camouflage, however, for with a section of about 4-ft. crown, and 1 on 2 side slopes, with many street and railway openings to be closed with temporary bulkheads of piling or sand-bags, it is utterly inadequate protection for a city of 400 000 population against a flood of a month or more in duration. A large part, perhaps the major part, of the necessity for the Caernarvan crevasse arose from the weakness of this levee, which no one dared trust.

The construction of the Bonnet Carre Spillway, which will no doubt be finished as one of the first steps of the Mississippi flood-control project, will greatly reduce the hazard at New Orleans from Mississippi River floods, but it has no beneficial effect on what is perhaps a greater danger; that is, hurricane floods from Lake Pontchartrain. This lake lies north of the city and has an area of 600 sq. miles. It is connected to the Gulf of Mexico by two large passes. With the rapid growth now in progress, the city will soon occupy all the land between the lake and the Mississippi River. Much of this area is less than 2 ft. above Gulf level, some of it being below mean tide. To protect the city against rises in the level of this lake a levee, much of which is not more than 5 ft. high, extends along the shore. Through this levee, leading into the heart of the city, are several canals, the banks of which are only 2 or 3 ft. high. There are no gates or other protection works where the canals pass through the levee.

The Gulf coast is subject, at not infrequent intervals, to high tides due to West Indian hurricanes, which sometimes raise the levels 10 ft., or more, above the ordinary levels. New Orleans has been especially fortunate thus far in hav-

ing escaped disaster from these storms. In 1915, the center of such a storm passed nearly over the city, but just enough to the proper side so that the wind blew from the city toward the lake, pushing back the water from the city. On the other side of the storm center, where the wind blew from the lake toward the land, great damage occurred. On the main double-track line of the Illinois Central Railroad the rails were lifted bodily from a fill as high as the levee protecting New Orleans, and were thrown over into a swamp.

The situation at New Orleans is quite similar to, but even worse than, that at the towns along Lake Okeechobee, which were so badly damaged by the storm that passed over Florida in October, 1927, and which suffered so terribly in the storm of September, 1928. It is greatly to be hoped that the engineers who realize the situation will be able to secure support for adequate protection before "the horse is stolen".

AMERICAN SOCIETY OF CIVIL ENGINEERS
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PAPERS AND DISCUSSIONS

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THE VIRGINIAN RAILWAY ELECTRIFICATION

Discussion*

By George Gibbs, M. Am. Soc. C. E.†

George Gibbs,‡ M. Am. Soc. C. E. (by letter).§—The discussion is confined chiefly to comments on electrical and power matters. None has been made on the purely civil engineering details of design or on methods followed in construction and application of the peculiarly electrical devices to the railway right of way. The writer hoped to have had suggestions from engineers who have the care of the physical plant of railways as to the effect of the presence of structures and appliances upon clearances and operating procedure. It is evident that the presence, everywhere, over or along the tracks of conductors designed to secure continuous physical contact by a device on the locomotive means an invariable location (within narrow limits) of these conductors with respect to the tracks and adequate supporting structures alongside. All these restrictions raise important and difficult problems of accommodation between right of way and electrical construction and it is important that they should be adjusted in the best possible manner between the interested parties in order to produce economy in first cost and maintenance.

The paper, presented to a Society which has not been especially interested in electrical devices, was intended primarily to stimulate interest and inquiry into a method of railway traction which is becoming increasingly important and which is, therefore, a matter of concern to engineers having to do with the design or care of every department of a railway. The writer hopes that, in spite of the absence of comment from members engaged in maintenance-of-way work, the paper will be found helpful to them and will assist in the further development of details best suited to the physical conditions and limitations of railway location.

While the contact devices of an electric traction system impose obstructions on the permanent way of a railway, electric operation permits steeper grades than are allowable with steam haulage, especially in the case of motor-car passenger trains on which can be concentrated an almost unlimited motive power.

* Discussion of the paper by George Gibbs, M. Am. Soc. C. E., continued from August, 1928, *Proceedings*.

† Author's closure.

‡ Cons. Engr.; Chf. Engr., Elec. Traction, L. I. R. R.; Cons. Engr., P. R. R., New York, N. Y.

§ Received by the Secretary, August 24, 1928.

Similarly, trains hauled by locomotives can be grouped for multiple control from one point when it is necessary to furnish increased tractive effort; in the case of steam traction the dual control of two locomotives is open to objection, as is well known.

Mr. Hogan* has raised a number of interesting questions in connection with heavy electric traction systems and methods. Some of these are rather outside the scope of the paper, but may be answered briefly.

He is interested in the "system" controversy. This is not the place to enter into a discussion of the relative merits of different electric systems, for the reason that the paper was intended to cover only the considerations and conditions which led to the adoption of a certain system as best adapted for the Virginian Railway. He takes exception to the remark that the "alternating-current system is the nearest approach so far to a general one".† The writer made this statement only in connection with a brief explanation of the trend of development of systems, beginning with appliances for light or comparatively short-distance haulage and leading up to those required for the heaviest character of trunk-line work over long distances. The distinction was made in order to show the reason for using high voltages in the transmission and the current-collecting devices at the trains for the latter services.

Some systems are limited in respect to the working voltage, and are, therefore, most suitable for light or short-distance work; but the alternating-current system, being flexible as regards working voltage, is adaptable for any character of traction. The word, "general", used by the writer, has no reference to the extent of present usage of systems, which is really a factor of little significance in determining on a system for a particular case. Many of the installations cited by Mr. Hogan can be considered only as examples of the progressive steps followed in the development and application of heavy electric traction. Therefore, to draw any conclusions from a catalog of such installations it is necessary to take into account both the dates at which they were installed and the local railway conditions surrounding each. As matters now stand, there is no one system in exclusive use, and this is as it should be. Developments should be allowed to continue along different lines and by different systems before being tied down to a standardization on one, which would preclude further useful advances in the art.

This point has been well brought out in the discussion submitted by M. Japiot,‡ who is one of the French railway officials responsible for the selection of a system for the French railways. He is a man of broad railway experience, a keen student of electric traction, has traveled much in the United States, and is unusually familiar with what has been done here as well as elsewhere in electric traction. He recognizes that European railway conditions are quite different from those in America and may require different methods for their solution. He brings out the important point, moreover, that the need for standardization on one system is not as great in America as it is in European countries, stating that,

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1581.
† *Loc. cit.*, p. 1582.
‡ *Loc. cit.*, April, 1928, Papers and Discussions, p. 1297.

"With the unrestricted liberty still prevailing in the American field, engineers in the United States have the opportunity to give each individual problem the most favorable solution. * * * standardization must always be a compromise between the advantages and drawbacks of the different systems of electrification for several various problems."

He goes on to say that "if any compromise had to be made at an early date (which does not seem to be probable), the single-phase overhead line might be adopted successfully in America." The writer is not arguing that question now, and merely wishes to state that the reasons in favor of the system which was adopted on the Virginian Railway were controlling for that case. Furthermore, it can be safely stated that no one connected either with the design of the installation or its successful operation on that particular railway, has found any reason to regret the decisions made.

Mr. Hogan* refers at some length to the considerations which led to the construction of an independent power plant by the Railway Company. The problem of power supply for the road was most carefully studied for the particular situation and character of load. All outside local sources of power were examined and it was found that no existing power company in that particular field was willing to submit a proposition which could be considered.

These definite facts, therefore, should dispose of the question for this particular case, and in stating this there is no intention of reflecting unfavorably on commercial power supply in general or in particular. As stated in the paper,† "doubtless, there is a field for commercial power companies, especially large networks, in the supply of power for heavy railway traction, * * *".

As an example, the Pennsylvania Railroad Company has recently closed a contract on satisfactory terms with an independent power company for its present and future single-phase power requirements, which contemplate very large energy demands for an extensive electrification plan. This power company, the Philadelphia Electric Company, has a large generating capacity from a number of plants, both steam and hydro-electric, tied together in a great distributing network of lines. It was in an unusually favorable position to take on a railway load, which contemplates electrification of both freight and passenger services with a high daily load factor. None of these conditions applies to the case of the Virginian Railway.

Further, Mr. Hogan objects‡ to the statement that "in the Eastern United States available water powers are few, and such as exist are not generally near the consumer, and are often not dependable in capacity." He thinks that this does not apply to the entire Eastern United States. This may be true for certain locations in the East and for near-by and, as a whole, rather limited power demands. However, the point is that the extension of electric traction generally should not be predicated on the availability of hydro-electric energy, and it is not necessary that it should. Water is often said to be a "free gift of Nature", but electric energy produced from it is far from being "free" and may, in fact, be very expensive at the point received. Doubtless railway electrification will grow in extent by reason of its advantages and economies, in certain cases, over steam haulage. It is from these viewpoints that it should

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1581.
† *Loc. cit.*, January, 1928, Papers and Discussions, p. 16.
‡ *Loc. cit.*, May, 1928, Papers and Discussions. p. 1582.

be examined. Fuel-burning, however, to produce electric energy must, in the nature of things, be depended on for the majority of these enterprises.

Mr. Hogan asks a number of questions* relating to details of the electrical apparatus of the Viriginian Railway installation. He refers to the capacity of the generator sets, stated as 10 000-kw., continuous, single-phase rating; the capacity of this generator would be greater, of course, if loaded three-phase. The turbine, however, is built to suit the load. Therefore, to state the case more accurately, if the output were three-phase the generator would be smaller and the power plant otherwise would be the same.

As to the type of motor used, Mr. Hogan asks whether the single-phase motor can be constructed so as to meet the requirements of this service. This is best answered by stating that on the Pennsylvania Railroad (where similar service as to grades and heavy trains and starting conditions will obtain on the Pittsburgh Division when electrified) the straight single-phase type of motor has been adopted, built, and tested, and the conclusion is that it will satisfactorily meet such service conditions.

There has been no difficulty experienced in the distribution of load between the driving-wheels that are coupled to the different jack-shafts of the Virginian locomotive units. Of course, there are times when one motor will slip its coupled wheels and the other coupled unit will not, but there is no difficulty in a practical way in starting and hauling trains on that account.

As to the necessity of using the rheostats in the handling of trains, other than during acceleration periods this is, in point of fact, not a necessity and is a very small practical factor anyway. Occasionally, an engineman may cut in the rheostat descending light grades when he wishes to operate at more than 15 miles per hour (the normal speed being 15 miles per hour descending grades). In such case, by using resistance, the motors will operate above synchronism, and a speed of 18 to 22 miles per hour can be secured. Under these conditions almost no energy is returned to the line, either at 15 miles per hour or at the higher speeds.

The question is also asked as to how much the two-speed characteristic of the locomotive influences the system load curve. It does affect it to some extent, but the difference is not controlling in its effect on the general character of the load curve or in the power plant capacity. Other considerations, such as definitely limiting maximum running speeds to a safe figure in handling these very heavy trains over the division in the desired time, are of more importance. It is unsafe, in this as in many other matters, to generalize from an incidental factor in establishing a desirable over-all solution for a particular case. As to the normal pressure maintained between the trolley wire and the collecting device on the locomotive, each pantograph carries two shoes 4 in. wide having centers 10 in. apart; the pressure of each shoe against the wire is set at 10 lb. Answers to other questions submitted by Mr. Hogan will be found in Mr. Hill's discussion† of the paper.

Mr. Potter‡ speaks of the great desirability of "regeneration" in moving down heavy grades, and refers—aside from energy savings secured thereby—to the difficulties attending the use of air-brakes on these heavy trains at such

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1583.
† *Loc. cit.*, April, 1928, Papers and Discussions, p. 1304.
‡ *Loc. cit.*, p. 1295.

times. He also mentions that when the issue is between the question of power demand and train movement, the latter is the important one, inasmuch as "transportation is the purpose of the railway". All this is true and well expressed. In the paper, the writer mentions that the regenerated energy on the Virginian was found to be more than 8% of the total used to operate the road. The latest figures, covering 12 months' operation, show that the actual value was 9.1%, as taken from the watt-hour meters on the locomotives. This is obviously an important amount of energy saved, but does not express all the advantages secured by "electric braking". Safe and smooth control of the 9 000-ton train on the 12-mile Kellysville Hill (1.4% average grade) has been found a most important result.

Mr. Ray* refers in an interesting way to the experience of his road, the Delaware, Lackawanna, and Western, in handling heavy freight trains by steam on a certain steep descending grade 17 miles long, where it is necessary to restrict movement to a speed of 15 miles per hour. This requires thirty-five brake applications and releases during the descent. In contrast to this complicated operation, J. W. Sasser, Superintendent of Motive Power of the Virginian Railway, states† that, under electric operation on his railway, brakes are only regularly applied once during the 131-mile run from Elmore to Roanoke (the entire electrified division). He also states that 100% increased life has been secured from brake-shoes over that previously obtained under steam operation, and that slide-flat wheels are of rare occurrence. It naturally follows that the car as a whole receives reduced wear and tear over the division, and that train delays, accidents, and derailments on account of defective brakes are rare. A prominent Western railway official, on a recent inspection of the Virginian installation, has commented on the remarkably smooth handling of these electrically operated trains over an undulating division and the absence of surges and jars in starting and while in motion. Also, the absence of jar in stopping, due to it being unnecessary to apply the automatic brakes, is noted; final stop is made with the straight air-brake on the engine only.

Mr. Litchfield‡ refers to a contributing cause of smooth operation from the constant-speed characteristics of the locomotives. By riding on the trains observers cannot fail to be impressed with this result.

Mr. Semenza§ is interested in knowing the relative weight and cost efficiencies of different types of electric locomotives. This is, in the writer's opinion, really a question for determination at a future time. The effort on the Virginian was to adopt initially a locomotive of tried capabilities and of rugged construction. Other reasons for the locomotive design adopted are given in the paper. Refinements in type, details, and weight reduction will naturally follow further experience here and elsewhere. It would seem that foreign engineers have been more interested than those in America in developing locomotive designs to secure maximum weight efficiency. In the writer's opinion, some European locomotives show undeniable complication and a par-

* *Proceedings*, Am. Soc. C. E., April, 1928, Papers and Discussions, p. 1309.
† *Bulletin*, American Railway Association, June, 1928.
‡ *Proceedings*, Am. Soc. C. E., April, 1928, Papers and Discussions, p. 1306.
§ *Loc. cit.*, p. 1303.

ing down of weights of parts to an extent which would be inadmissible under American railway conditions.

Mr. Ofverholm* comments on certain differences between Swedish and American practice in the design of the distribution systems of electric railways and in the provisions adopted to prevent disturbances in near-by telephone and telegraph wires. The information he gives is interesting, but it is unsafe to conclude from the particular to the general for the preferred solution of complicated cases. Swedish electrifications are quite extensive and have been planned to conduct, successfully, traffic which in some cases is heavy compared with general European practice, but is always light as compared with American practice. They are especially very light as compared with the train loads dealt with in the Virginian Railway electrification. The treatment adopted by foreign engineers, therefore, for details can hardly be expected, in all cases, to fit in with American ideas and the radically different traffic conditions here.

Mr. Budd* is undoubtedly correct in stating that "on most of the railway mileage of the country * * * traffic density is not great enough to pay a return on the cost of electrification sufficient to make the investment attractive". He refers to the constant improvement made in the efficiency of the modern steam locomotive, both in capacity and economy, which makes it difficult to show the same advantages for electric locomotive operation over steam as was the case some years ago. This is a true statement and emphasizes the importance in making a thorough investigation of all factors governing a proposed use of electric instead of steam operation as applied to the particular case in hand and the danger of drawing the conclusion that if electric traction has been found advantageous in one location it would be equally so in another. An analysis of the individual problem, therefore, should always be made beforehand and by competent authorities in railway operation generally and in the special technical features connected with the two methods of operation. The Virginian Railway was confronted with the necessity of a very extensive physical rehabilitation of its property in order successfully to conduct its rapidly increasing business, and it became a question of whether it would be better to secure the increased capacity by a continuation of steam haulage with expensive additions to the main tracks, to get the best obtainable road capacity from steam locomotives; or, on the other hand, to make its present single main track adequate for a long time by using electric locomotives of unlimited capacity at a greater running speed. Electing to do the latter, the Company obtained a form of motive power which insured maximum hauling capabilities and sufficient for present needs. It still has the possibility of obtaining, when needed, additional road capacity by double-tracking.

Mr. Budd's questions regarding the type of electric locomotive used are answered elsewhere. The Virginian is not tied down to any one particular type. If in the future it should be found advantageous to use another, it can be done without in any way changing the main and expensive features of the electrification, namely, the power plant, the transmission lines, and the distribution system over the tracks.

* *Proceedings*, Am. Soc. C. E., April, 1928, Papers and Discussions, p. 1301.

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HYDROSTATIC UPLIFT IN PERVIOUS SOILS

Discussion*

By Messrs. J. Albert Holmes and E. W. Lane.

J. Albert Holmes,† M. Am. Soc. C. E. (by letter).‡—The author, after careful experimentation, prolonged study, and weighing of evidence, has placed before the Engineering Profession the data in a problem which he has ample reason to believe embodies a correct interpretation of the facts. Still, considering the weight of evidence in the earlier experiments,§ the author probably hesitated long and re-weighed the evidence with great care before reaching so divergent a conclusion.

Mr. Parsons states‖ that his research was made "to determine the hydrostatic uplift on the base of a structure, founded on a pervious soil, when there is no loss of head due to velocity of flow". This is static head, acting by mere weight without motion. There was some replacement by water when pistons were actuated in the apparatus used by Mr. Parsons. The pressure, when applied to the water above the sand, must necessarily build up throughout the whole body of the sand, not only to the depth of the piston end, but to the bottom of the chamber, before actuating the piston.

The soil particles in a bed of pervious material must have appreciable size, otherwise the material will be impervious. Mr. Parsons refines the matter minutely when he states¶ that the resultant of pressure of a particle of soil in contact with the base of a structure is upward. This is so, especially when the contact is but a point, since it could not be much more than a point. Rather than any considerable part of the base of a structure being in contact with the pervious soil particles, it would seem more likely to be in contact with water.

* Discussion on the paper by H. deB. Parsons, M. Am. Soc. C. E., continued from October, 1928, *Proceedings*.

† Hydr. Engr., Pearse, Greeley & Hansen, Chicago, Ill.

‡ Received by the Secretary, August 8, 1928.

§ *Transactions*, Am. Soc. C. E., Vol. LXX (December, 1910), p. 364.

‖ *Proceedings*, Am. Soc. C. E., April, 1928, Papers and Discussions, p. 941.

¶ *Loc. cit.*, p. 955.

The writer's interest in the problem of hydrostatic uplift relates to dams, and more particularly to earth dams where there is flow through the soil and a hydraulic gradient.

In all hydraulic experiments with soils, the presence of air is a disturbing factor affecting flow. Air is also present in the ground under dams and, of course, affects seepage rates there. An instance is recalled where air escaping upward through the water from an isolated mound of original ground, kept ice from forming just above on the core pool of an earth dam during a cold winter.

E. W. LANE,* M. AM. SOC. C. E. (by letter).†—The profession is greatly indebted to the author for giving to it the results of such thorough experimentation on a subject which is of great importance, but of which so little is known. The application of the experiments is not confined to dams, because, judging from the number of cases which have come to the writer's attention of buried tanks, cisterns, and even septic tanks being lifted from their positions by upward pressure of the water acting through the surrounding soil, the costly accidents resulting from a neglect of this pressure must be legion.

For many years the writer has been interested in the effect of upward pressure on dams on porous foundations. Some information was available on the unit pressure beneath dams, but the writer could find only one attempt to determine the area on which the pressure acted.‡ The writer did not regard these experiments sufficiently conclusive, and, therefore, made a few of his own. The method used was very similar to that used by Mr. Parsons in his low-head tests. The bottom of a large vessel (Fig. 1§) was filled with sand. A conical depression, the size of a smaller vessel, was scraped in the sand and filled with paraffin, which had been heated just above melting temperature, in order that it would make a contact with the sand similar to concrete poured on a gravel base, without running deeply into the voids. The depression was made conical to prevent the entraining of air beneath the smaller vessel. While the paraffin was still liquid, a smaller vessel with vertical sides was set into it, and the paraffin allowed to harden in contact with the inner vessel. This vessel was then filled with water nearly to the top, and water was added slowly to the outer vessel until the inner one floated.

The results were not developed quantitatively, since the height of water in the outer vessel (with respect to the inner one) which was necessary to lift the inner vessel, was very little more than that necessary to float the inner one after being lifted free from the sand. It was evident, therefore, that the pressure through the sand acted on practically the entire area of the base of the inner vessel. The slight difference in height in the two cases might easily be due to friction in breaking the contact of the paraffin and the sand adhering to it and the main body of sand. This difference also includes the discrepancy, if any, due to a time element in the transmission of pressure through

* Associate Engr., U. S. Engr. Office, Baltimore, Md.

† Received by the Secretary, October 22, 1928.

‡ "Pressure, Resistance, and Stability of Earth," by J. C. Meem, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. LXX (1910), p. 352.

§ *Proceedings*, Am. Soc. C. E., April, 1928, Papers and Discussions, p. 943.

the sand as the water was poured into the outer vessel. If the writer were to repeat the experiments, he would adopt Mr. Parsons' method, and siphon the water from the inner vessel, instead of adding it to the outer one, as the former method eliminates all question regarding a possible time of transmission of pressure through the sand. However, error from this source could not have have been appreciable, since both it and the friction in breaking contact with the bottom are included in the very slight amount the inner vessel was lifted when the contact with the sand bed was broken.

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MODERNIZING THE SUBURBAN TRANSIT OF THE METROPOLITAN DISTRICT

Discussion*

BY HAROLD M. LEWIS, M. AM. SOC. C. E.

HAROLD M. LEWIS,† M. AM. SOC. C. E.—This paper has covered the requirements of the suburban transit situation in the New York Region very comprehensively in few words. The author has presented conclusions which are obviously based on careful study. In general, they are supported by the survey of existing conditions and of past and probable future needs which has been made by the Staff of the Committee on a Regional Plan of New York and Its Environs. The speaker believes that the proposed routes developed by the Regional Plan will also fit in with such a program as Mr. Stuart has presented.

In addition to various local transit facilities, the Region is supplied with a series of rapid transit lines now confined almost entirely to New York City, the suburban rapid transit system provided by the railroads to serve the so-called "commuter", and the trunk-line railroad system. The functions and facilities of these three types of transportation overlap to a considerable extent, but in laying down a program for future development it is possible to discuss them as separate systems.

As the commuter is now served almost entirely by the railroads, it is obvious that the commuter problem must necessarily be solved in conjunction with the railroad companies and through the co-operation of those companies and the public agencies representing the people who are to use the lines.

The railroads have built up a large network of passenger facilities in the Region. (See Fig. 3.) The commuter service over these lines is served by twelve principal terminals. Of these, only two—the Grand Central Terminal and the Pennsylvania Station—are located in the Borough of Manhattan, and commuters are discouraged from using the latter because of a much higher commutation fare than can be obtained *via* the Hudson and Manhattan

* Discussion of the paper by Francis Lee Stuart, M. Am. Soc. C. E., continued from November, 1928, *Proceedings*.

† Executive Engr., Regional Plan of New York and Its Environs, New York, N. Y.

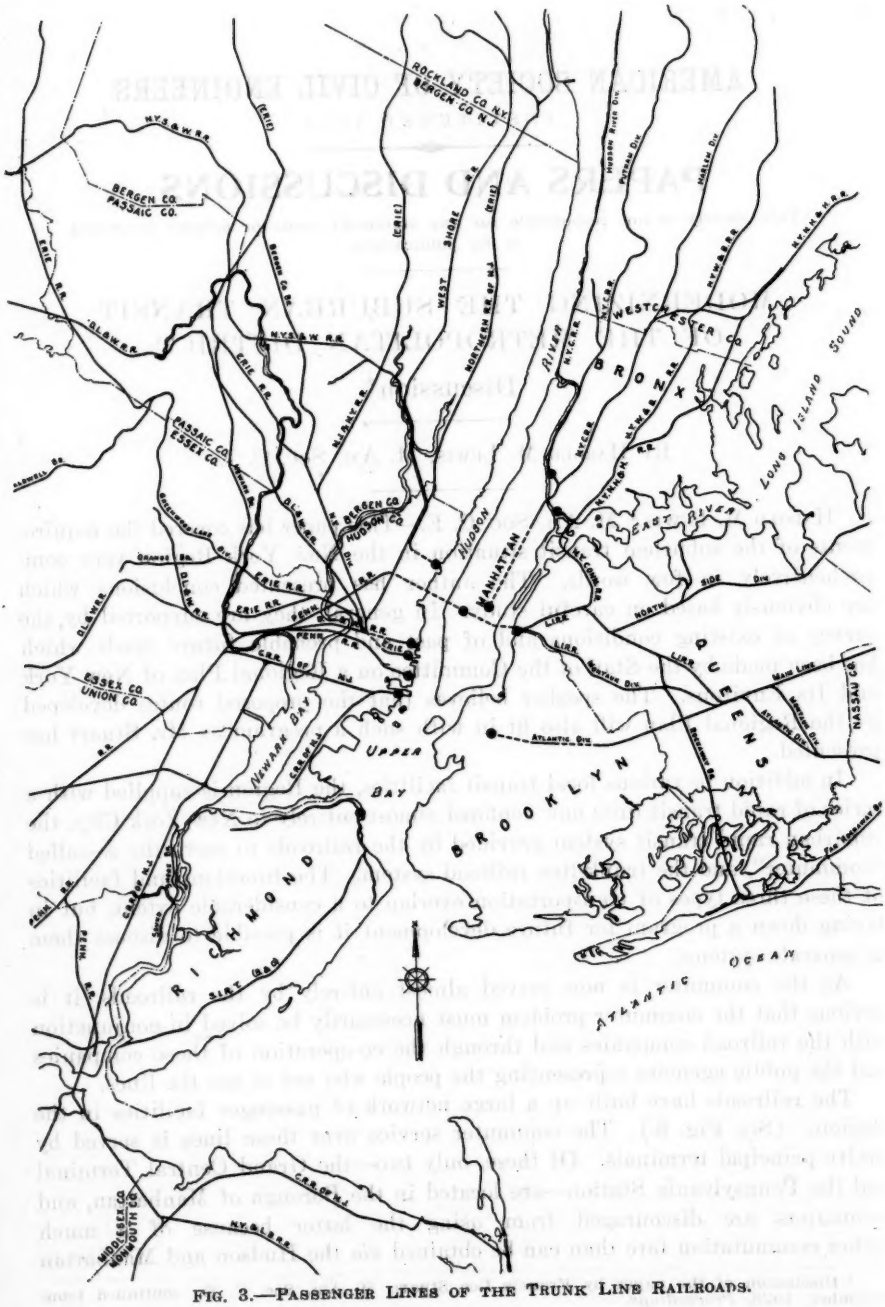

FIG. 3.—PASSENGER LINES OF THE TRUNK LINE RAILROADS.

Company Tunnels. The Borough of The Bronx has two terminals, and Queens, Brooklyn, and Richmond each have one, although the commuter traffic to the Long Island City Terminal in Queens is only a fraction of what it was before the Long Island Railroad System was carried under the East River to the Pennsylvania Station. The other five terminals are located on the New Jersey shore of the Hudson River. All the metropolitan passenger terminals are shown by large dots on Fig. 3. The only rail connection between the New Jersey and New York sides of the river is supplied by the Pennsylvania Railroad Tunnels.

How do these lines serve the existing passenger movement? It is generally known that the present passenger movement within the New York Region is concentrated on the Borough of Manhattan. This movement totaled in 1924 about 2 181 000 persons entering Manhattan during the twenty-four hours of a typical business day. An analysis of the means of transportation used by these individuals will show the part which the railroads played in providing the necessary service. Fig. 4 shows the geographical distribution of this passenger movement as well as the means of transportation used under the following four classifications: Rapid transit; surface cars; railroads; and a total of those by ferries and vehicular and pedestrian bridges. Many of these persons used two or more types of facilities in completing their journey; they are classified in this study only under that type by which they gained access to Manhattan.

It is indicated that the number of ferry passengers from New Jersey was about ten times the number entering by railroad, which was limited to those who used the Pennsylvania Station. The number that entered from New Jersey by the Hudson and Manhattan Company Lines, which have been classified as a rapid transit facility, was about 8½ times as great as those who entered by railroad. The passengers entering from the north and east included a large intra-city movement. The figures for those sectors, therefore, do not show as clearly the transportation problem of the commuter, but they do show that only a small percentage of the passengers from those directions entered Manhattan *via* railroad lines.

A future picture of passenger movement has been prepared by estimating the probable interchange movement between estimated areas of 500 000 population. This shows a continued concentration on Manhattan, but a much greater movement around that Borough and increased inter-communication between other parts of the Region. Most of the passenger movement with a length of haul of more than 3 or 4 miles must be taken care of by a suburban rapid transit system.

Short-haul travel in the central areas must be served primarily by the rapid transit system, which is outside this discussion. The speaker believes, however, that some way must be found of bridging the State boundary line down the center of the Hudson River sufficiently to extend the present rapid transit system in New York City so as to serve the communities along the western shore of the Hudson River between Bayonne and Englewood, N. J. The separate parts of a proper suburban transit system should be available for most of the local rapid transit demands within Metropolitan New Jersey.

That part of the present passenger movement that is carried by the railroads is approximately proportional to the passenger train movement over the existing lines. A traffic flow diagram (Fig. 5) prepared on this basis in 1924 shows very clearly the railroad lines which carry the heavy suburban traffic. Most of this is seen to be to or from points within thirty miles of New York City Hall. Those railroads which carry a great preponderance of commuter traffic show a very large increase in passenger train service as the lines approach the central congested area. This is particularly noticeable on the lines of the Long Island Railroad.

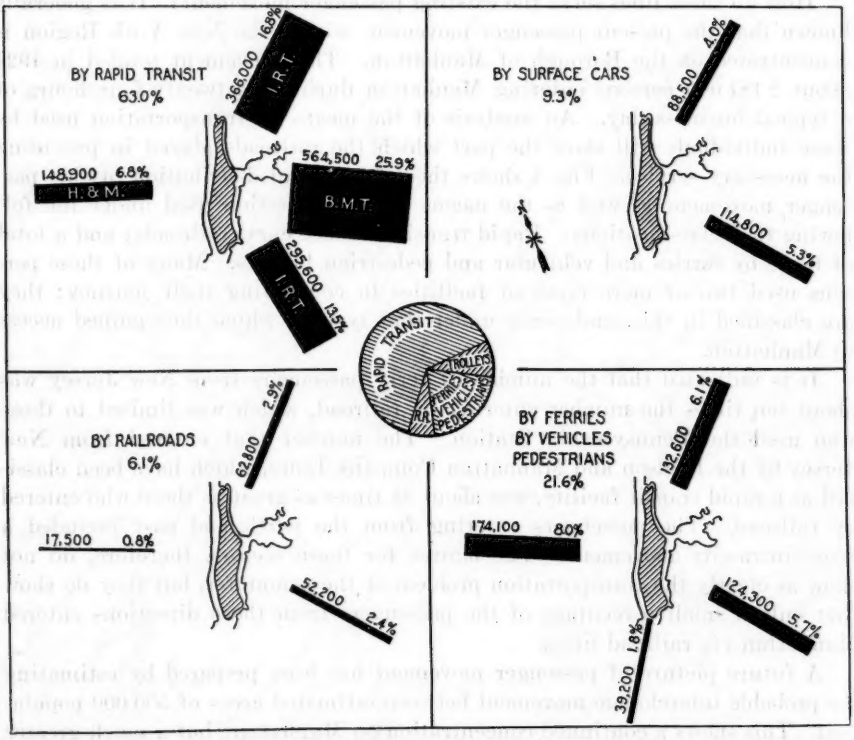

FIG. 4.—MEANS OF TRANSPORTATION USED BY PERSONS ENTERING MANHATTAN DURING 24 HOURS ON A TYPICAL BUSINESS DAY IN 1924.

Traffic in the central part of the Region has been shown at a reduced scale on a separate diagram (Fig. 6). This shows the relative importance, from a traffic viewpoint, of the various terminals already mentioned. In number of trains the Pennsylvania Station, with 604 trains daily, was far in the lead. (The total traffic at this terminal is the sum of the trains shown on Fig. 6 as entering over the Long Island Railroad and those entering over the Pennsylvania Railroad.) Next came the Grand Central Terminal with 492 trains, while the Flatbush Avenue Station of the Long Island Railroad ranked third, with 459 trains daily.

Defining the commuters as passengers who traveled on a lower fare than that charged for a single trip, and excluding the passengers of the Staten Island Rapid Transit Railroad, which operates entirely within New York City,

about 160 800 000 were carried to and from New York Metropolitan Terminals in 1924. This type of traffic had doubled in 9 years, as against a 13-year period within which the total railroad passenger traffic to and from such terminals

FIG. 5.

had doubled. This increase of commuter traffic represented average annual gains of 7.5% over a 10-year period, the great increases having been on the Long Island Railroad, where there was an average annual gain of 14.2 per cent. A corresponding figure for commuter traffic from the north showed an average annual gain of 9.8%; from New Jersey the gain was 5.0 per cent.

This traffic was influenced to a considerable extent by the type of service provided, which is reflected in the fares charged and the running schedules.

These have been shown in map form by drawing "contours" through points of equal fare or with the same time schedule to and from New York City terminals. In Fig. 7 rates are computed from the monthly commutation fares by dividing the total yearly charge by 600, based on 50 one-way rides each month. The shaded area is that served by the New York City Rapid Transit System. In Fig. 8, time is computed by averaging the commuting time on morning and evening trains. Twenty minutes are added to the time to and from the Harlem River Station on the New York, Westchester, and Boston Railroad.

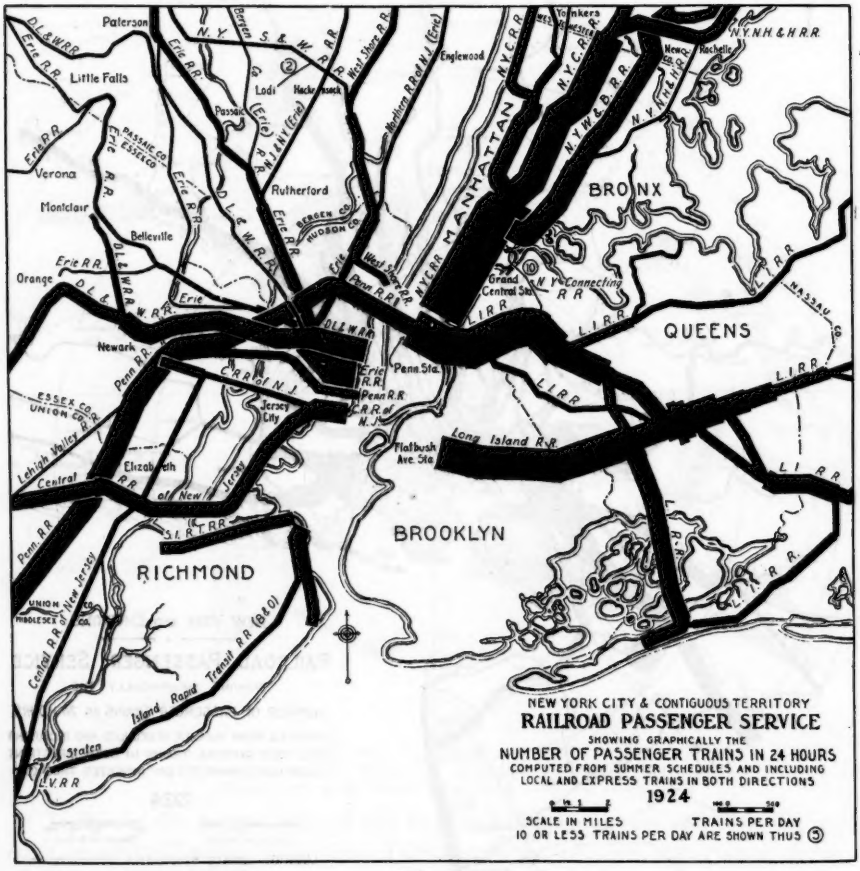

FIG. 6.

In both cases it appeared that, within 20 or 25 miles of New York City Hall, the necessity of crossing the Hudson River to reach points along the westerly shore has added a considerable item in both commuter fare and time of travel above that required for points east of the Hudson River and at equal distances from Southern Manhattan. The additional fare was about 5 cents a single trip, and the additional time was about 15 min. At points farther from the center of the Region this differential tends to disappear. The fare "contours" are quite regular, but show a reduction in rates where competing

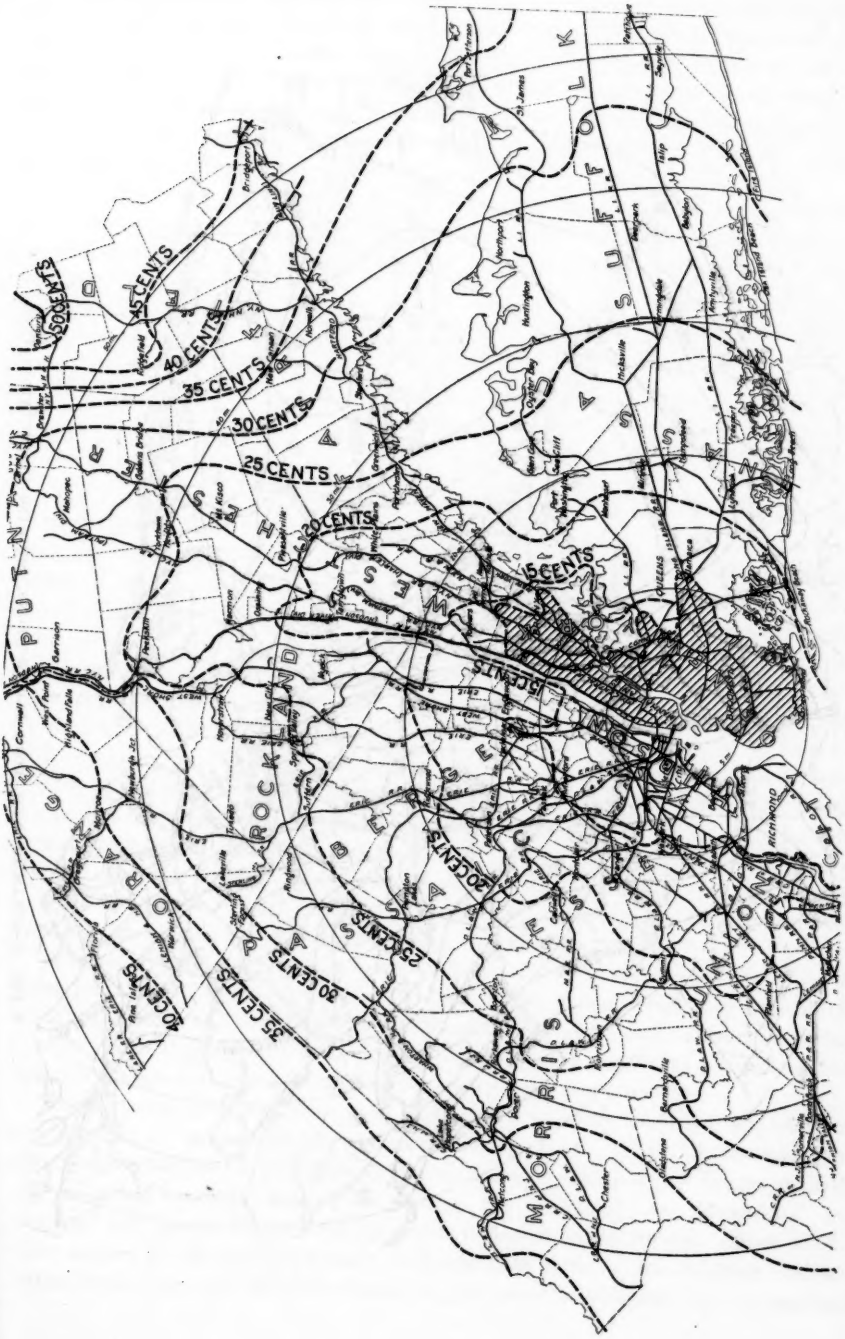

FIG. 7.—PLAN OF NEW YORK AND ENVIRONS SHOWING RAILROAD COMMUTING RATES.

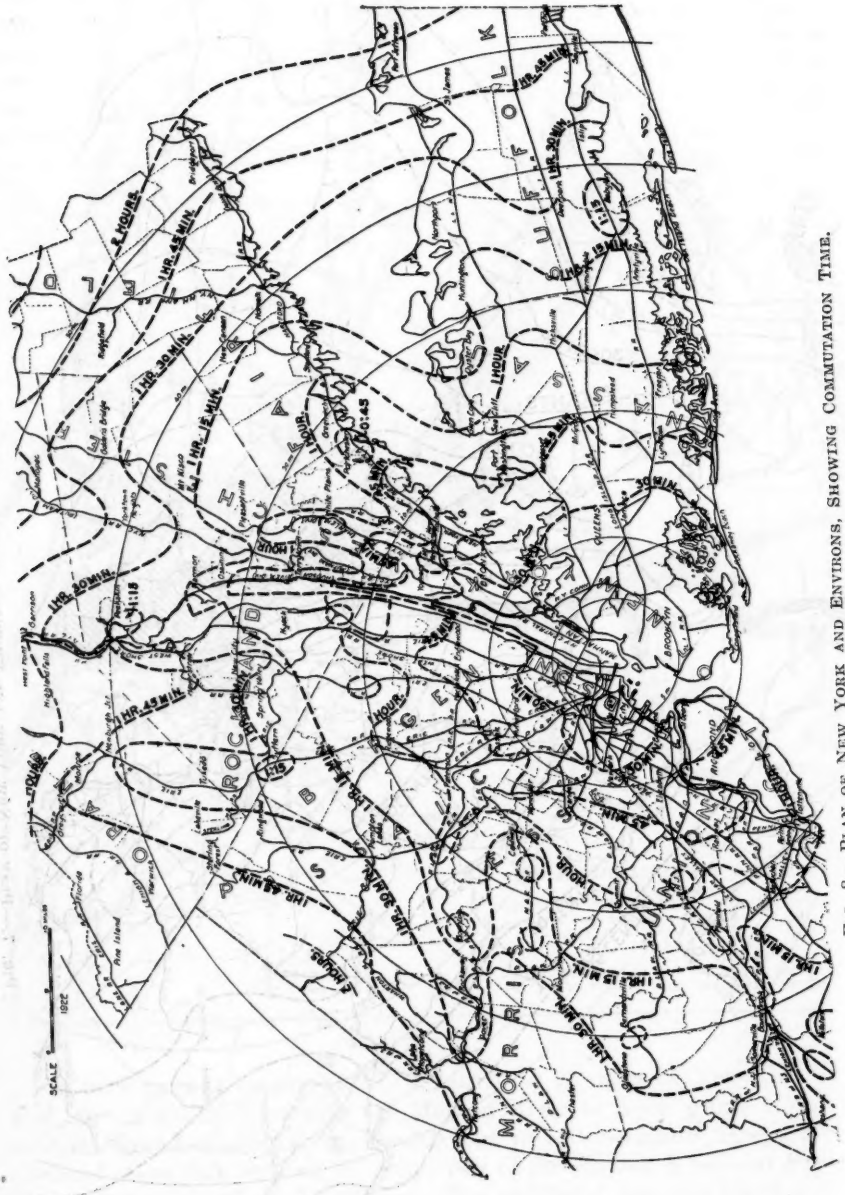

FIG. 8.—PLAN OF NEW YORK AND ENVIRONS, SHOWING COMMUTATION TIME.

lines serve the same territories. The fares shown in Fig. 7 for the New York, New Haven and Hartford Railroad were those in existence before the increases in rates allowed that Company in August, 1925. The time "contours" are much more irregular, largely due to the express service provided at certain points. With a comprehensive suburban rapid transit scheme serving the areas within 20 to 30 miles of the center of New York, the commuting fares and times, for communities therein which are equi-distant from the center, should be approximately the same.

An important question to be answered in laying out a comprehensive suburban transit system is: "How can the maximum use be made of existing facilities in providing adequate service for the future requirements?" The primary needs are two:

(1) New distributing lines in the central congested areas. These should traverse not only the Borough of Manhattan, but also the adjacent areas in New Jersey, The Bronx, Brooklyn, and Queens.

(2) A single operating system under some type of unified control to serve the entire suburban rapid transit area. Only in this way can an intensive use of all facilities and a two-way rush-hour traffic over the expensive lines in the central area be assured.

The complete suburban rapid transit plan to be included in the Regional Plan proposals does not call for much new construction. It is intended that most of it could be developed on, alongside, over, or under existing railroad rights of way. The first step would be the construction of certain new joint distributing lines in the central areas largely corresponding with the suggestions made by Mr. Stuart. This includes an interstate loop passing through Southern Manhattan and the easterly part of Hudson County, New Jersey. This loop is connected to the north with the various divisions of the New York Central and New York, New Haven and Hartford Railroads, and to the east with the Long Island Railroad System. An extension of the New York, Westchester and Boston Railroad from the southerly terminus in The Bronx to and across the northerly part of Manhattan is also included. This could be connected later with an additional north and south route on the west side of Manhattan. It will be seen that there is nothing original in the various elements of this plan, which is a co-ordination of proposals already put forward by other agencies who have studied this problem.

A great advantage of the proposed layout would be the great flexibility in operation that it would permit. It would enable trains from any one of the suburban sectors to be routed through Manhattan to any other suburban sector. It would also make possible, if desired, a loop operation from a single sector through the central business areas and back to the same sector.

The ultimate plan would expand this system to serve all those communities within what is considered the suburban rapid transit area. It includes two additional north and south lines in Manhattan to take care of future growth, and a rapid transit route connecting the Borough of Richmond *via* Bayonne and Jersey City, with the central distributing system. Most of the other routes in the system simply indicate that part of the existing railroad system over which the unified control of commuter service should be furnished.

FIG. 8.—PLAN OF NEW YORK AND ENVIRONS, SHOW

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A PROPOSED FORMULA FOR COLUMNS

Discussion*

BY MESSRS. HENRY S. PRICHARD, E. H. SALMON, C. N. ROSS, K. L. DEBLOIS, and EDWARD GODFREY

HENRY S. PRICHARD,† M. AM. SOC. C. E. (by letter).‡—The writer has checked the development of Equations (8),§ (10),‖ and (18),¶ and considers Equation (18), which he believes to be new, a valuable contribution to the theory of columns and a good guide whereby, in conjunction with experiments, experience, and common sense, to develop and check simple formulas for columns. The author states that the development of Equation (8) is not strictly rigid in that a certain numerical function in the denominator which (depending on conditions) varies between 9.6 and 9.8696, has been taken as 9.87. As he shows, the proportional numerical error in any case, as compared with rigid theory, is very small. It must be considerably less than 1% and probably is seldom if ever much greater than the case the author cites of the column with $\frac{l}{r} = 100$.§

At the risk of being thought hypercritical, the writer would point out that if 9.84 is used wherever the author has used 9.87 in the development of Equation (18), it will cause an even smaller departure from theoretical accuracy.

For a special case, the author has developed his much simpler Equation (19).** To obtain a second partial check, but one that is highly satisfactory because it is simple, is wholly arithmetical, and uses a different method requiring none of the care and clear thought necessary in following a complicated analysis, the writer omitted the factor of safety in Equation (19), thereby

* Discussion of the paper by T. F. Hickerson, M. Am. Soc. C. E., continued from October, 1928, *Proceedings*.

† Analytical Engr., Am. Bridge Co., Pittsburgh, Pa.

‡ Received by the Secretary, August 17, 1928.

§ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1438.

‖ *Loc. cit.*, p. 1439.

¶ *Loc. cit.*, p. 1440.

** *Loc. cit.*, p. 1442.

using 36 000 instead of 16 000; determined the value of $\frac{P}{A}$; took from, or in some cases deduced from, the author's data the numerical value of each symbol for a given case in which $\frac{l}{r}$ is 50; substituted these values in Equations (8) and (10); and found that $f = 36\,000$ lb. For a similar case in which $\frac{l}{r} = 100$, f was found to equal 36 002 lb.

A rational formula which limits the maximum unit load, for a column with pivoted ends and an unintentional sinusoidal bend, is as follows:

$$\frac{P}{A} = \frac{\pi^2 E r^2}{l^2}\left(\frac{x}{y+x}\right) \quad \ldots\ldots (35)^*$$

in which, the unintentional eccentricity at the center $= \frac{l}{x}$, and the greatest deflection not considered excessive $= \frac{l}{y}$. For $E = 30\,000\,000$, $x = 700$, and $y = 300$:

$$\frac{P}{A} = \frac{207\,260\,000}{\left(\frac{l}{r}\right)^2} \quad \ldots\ldots (36)^*$$

If Equation (36) were applied to the paper with a factor of safety of $2\frac{1}{4}$, deflection instead of stress would become the critical consideration for columns with pivoted ends at $\frac{l}{r} > 96$ (approximately). Of course, the judgment of engineers as to the amount of bend liable to occur and the amount of deflection to be tolerated will differ somewhat but probably not very much. Where a column lies in a horizontal position it has a deflection from its own weight which should also be considered in limiting P on account of critical deflection.†

In actual practice rounded or pivoted ends are seldom if ever used, but (except for the effect of friction) pin ends are about the equivalent of pivoted ends.

In tests of full-sized columns, in which the loads are quiescent and applied gradually and without shock or vibration, friction, when the eccentricity is small, so restrains the ends that pin-ended columns stand much higher test loads than pivot-ended ones, albeit the restraint may only be maintained by a small margin which could easily be overcome by a lively load and would certainly be overcome by any considerable eccentricity.‡ In practice it is best not to place reliance on restraint exerted by friction on pin-ended columns.

* *Transactions*, Am. Soc. C. E., Vol. 89 (1926), p. 1242.
† *Loc. cit.*, p. 1264.
‡ *Loc. cit.*, pp. 1246, 1247, and 1266.

Framed structures in which each member receives its entire load from a pin at each end or from some equivalent arrangement are very few. For instance, in nearly all "pin bridges" only part of the members are completely pin-connected. In the great majority of structural frames all the members are rigidly connected so that each member is subjected at its ends to the bending moments of the forces from other members acting on it. This causes secondary stresses in each member in addition to the direct stress indicated by the "stress diagram".

Prior to the Twentieth Century, secondary stresses due to the rigidity of joints generally received scant attention. Some of the early texts did not even mention the subject* and others dismissed it with the statement that the angular change caused by this source of stress is so small that it may be ignored.† In practice, the effect of such secondary stresses was generally neglected.

However, with the heavy loads and large structures frequently encountered in modern practice, the secondary stresses from rigidity of joints, as indicated by the theory of elastic flexure, are occasionally found to be so great as to cause grave concern. In so far as it is pertinent to the subject outlined by Professor Hickerson, the writer would like to call attention to a commendable paper by Professor Cecil Napier Ross.‡

Every structure under the specified loading has, or should have, a margin of safety. In judging as to the maximum load a structure would actually stand in case of emergency, the status of the maximum with reference to the critical load is one of the points which should be considered.

The analyses by the author, by Professor Ross, and by the writer, are based on perfect elasticity. There are probably no limits within which commercial steel bodies are perfectly elastic before they have been subjected to cycles of stress, but by such cycles seemingly perfect elasticity can be developed in good quality structural steel members without serious defects, such as flimsy details, within fairly wide limits at the expense of more or less permanent set, according to conditions. In the writer's judgment, what these limits will be for any case can be determined fairly well by scientifically conducted specimen tests.§

Within the "Useful Limit Point," or "(U. L. P.)",‖ the permanent set in steel of good quality which is acquired in perfecting the elasticity is not prohibitive, although sometimes considerable, and does not seriously impair calculations based on a modulus of elasticity of 30 000 000.

The author's Equation (18) requires the eccentricity of application to be the same at each end and to the same side of the axis, but otherwise it is entirely general. By considering for simplicity that $\frac{c}{r}$ is constant, by making

* See, for instance, "The Stresses in Framed Structures," by A. Jay Du Bois, 1896.

† "Modern Framed Structures," by J. B. Johnson, and others, 1896, p. 165.

‡ "Equivalent Eccentricities Due to Secondary Stresses," by C. N. Ross, *Transactions*, The Institution of Engrs., Australia, Paper No. 1, Vol. VIII (1927), p. 8; see, also, *Engineering News*, February 25, 1909, p. 205; and *Transactions*, Am. Soc. C. E., Vol. 89 (1926), p. 1420. Important citations from the original paper are given in Prof. Ross' discussion (see p. 2729).

§ *Transactions*, Am. Soc. C. E., Vol. 89 (1926), pp. 1217, 1220, and 1236.

‖ *Loc. cit.*, Vol. LXXXIII (1919–20), p. 1618.

fairly reasonable assumptions as to the extremes of accidental eccentricity at the ends and curvature of axis between the ends, by assuming that $f = 36\,000$ lb. per sq. in., and then applying a factor of safety of $2\frac{1}{4}$, the author derived Equation (19) which is applicable with precision to a particular set of cases. Equation (19) is complicated and burdensome so he devised Equation (21)* which from $\frac{l}{r} = 0$ to $\frac{l}{r} = 150$ gives a very close approximation to Equation (19). The author proposes Equation (21) for determining the value of mild steel columns (with pivoted ends or their equivalent) and states that 36 000 lb. per sq. in. is the yield point of the material.

For columns similar to the small ones cited by the author* as tested by Tetmajer and for nickel steel, silicon steel, chrome steel, high carbon steel, and certain other special steels, the assumption of 36 000 lb. per sq. in. on which his factor of $2\frac{1}{4}$ depends, is not too high, but for steel not special (which constitutes the great bulk of the product of the mills) the factor of $2\frac{1}{4}$ would seldom be realized, as shown by Tables 16, 17, 18, 19, and 20, in the Final Report of the Special Committee on Steel Columns and Struts.† There are great differences in the actual factor of safety of short columns proportioned by any of the formulas in ordinary use or, in fact, by any formula which gives the same value for f for the steel that can be furnished under any one of the various specifications for structural steel. To illustrate this point Table 1 has been prepared.

There are a number of facts which it is well to remember when considering the subject of columns and column formulas. These may be listed as follows:

(*a*) The strength of steel varies greatly, even when nominally of the same grade.

(*b*) The condition that $\frac{P}{A} >$ crushing resistance of steel means failure (but the fact that $\frac{P}{A} <$ crushing resistance does not insure safety).

(*c*) The condition that $\frac{P}{A} > \frac{\pi^2 E}{\left(\frac{l}{r}\right)^2}$ means failure whether the steel is of high carbon or low carbon or alloyed with nickel, silicon, or chrome. The value of $E = 30\,000\,000$ is about right for all these steels and f in this expression is not even a matter for consideration, as $\frac{P}{A}$ is herein limited by the extreme of elastic stiffness only.

(*d*) Local weakness, whether from poor design, lack of stiffness, bad defects in material, or other cause, may result in failure in a poorly proportioned column even where, in a well-proportioned column, failure would not take place.

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1444.
† *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919–20), pp. 1619–1623.

(*e*) The condition, $f >$ elastic limit, does not necessarily mean failure, especially if by plastic deformation the column obtains relief from excessive stress. For instance, if by reason of secondary stresses, f, at the end of a column and near its extreme fibers, is greater than the elastic limit, the resulting plastic deformation and subsequent recovery will permanently reduce the extreme magnitude of the secondary stresses, provided it does not fail from local weakness and, further, provided the proportion which the live load stress is of the total is not too great. When the greatest stress is near the middle of the column, the relief from secondary stresses afforded by plastic deformation and subsequent permanent set is countered by the acquirement of permanent deflection which is detrimental; the detriment may be very slight, or it may be very great, depending on the amount of permanent deflection acquired and the stiffness or limberness of the column.

TABLE 1.*—FLAT-ENDED COLUMNS OF H-SECTIONS AND OF ONE WEB AND FOUR ANGLES, WITH $\frac{l}{r} = 50$.

(Results are in pounds per square inch.)

Tables.†	Number of columns.	Section.	Specimen Tests.		Full-Sized Columns.	
			Average ultimate strength.	Average U. L. P., or average drop of beam.	Ultimate strength.	Useful Limit Point (U. L. P.).
19 and 22	3	8-in. H-Column by 32 lb.	61 500‡	Useful Limit Point.‡	38 000	35 000
					38 000	34 500
					37 500	34 500
19 and 22	3	8-in. H-Column by 62 lb.	57 900‡	Useful Limit Point.‡	36 100	31 000
					36 000	32 500
					33 300	30 000
19 and 22	3	8-in. H-Column by 91 lb.	56 400‡	Useful Limit Point.‡	27 100	19 000
					24 600	21 100
					22 600	24 000
16 and 22	3	4 angles, 5 by 3-in. by 5/16-in. 1 plate, 6-in. by 7/16-in.	58 900§	Drop of beam.§	33 000	29 000
					32 800	29 200
					34 000	28 300
16 and 22	3	4 angles, 5 by 3-in. by 9/16-in. 1 plate, 6-in. by 9/16-in.	59 500§	Drop of beam.§	32 400	28 300
					29 700	25 000
					29 000	25 000
					28 900	24 000
					38 300	

* Comp. from Final Report of Special Committee on Steel Columns and Struts, *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919-20), p. 1583.

† *Loc. cit.*, pp. 1619, 1622, and 1629.

‡ U. S. Bureau of Standards specimen tests.

§ Mill specimen tests.

(*f*) If the stress exceeds the U. L. P. and the live load stress is oft repeated, the range of stress between live load on and off may be sufficient to cause failure from fatigue, instead of the acquirement of a raised field of seemingly perfect elasticity. Under a somewhat greater range, failure from fatigue may occur under reversed stress oft repeated.

(*g*) Load, stress, and stiffness, under the conditions which obtain when the column is designed, are not the only important points: The liability to unusual loading in emergencies, to increase in future normal loading, and to deterioration of material from rust or from over-straining are also important considerations.

E. H. SALMON,* ESQ. (by letter).†—It is generally admitted that the secant formula, although theoretically correct for an eccentrically loaded column, is inconvenient for practical application. Not only is this true, but it is now recognized that the effects of initial curvature, although similar, are not identical with those due to eccentricity of loading. Professor Hickerson takes both causes of weakness into account, and by his assumption‡ that the final shape of the bent column is a parabola, instead of a sine curve, replaces the secant by an algebraic expression. This assumption would appear to be perfectly legitimate; in fact, William Cain, M. Am. Soc. C. E., has stated,§ that this assumption gives a closer approximation for small values of $\frac{l}{r}$ than is obtained by expanding the secant and neglecting higher powers than the second.

The author shows that his equation gives very similar results indeed to an equation of the writer,‖ which was based on the assumption that the initial curvature is parabolic. The advantage of the latter assumption is that the deflections due to the initial curvature and eccentricity are functions of the same angle, that is, of sec $\frac{1}{2}\frac{l}{r}\sqrt{\frac{P}{A\,E}}$, but it involves the secant. The writer showed, however, that provided the factor of safety on P_E (Euler's crippling load for the column), was not less than 4— and in the majority of columns used in bridges and buildings it is much greater than this—the secant could be replaced by a straight-line law; that is, using Professor Hickerson's symbols, Equation (9)‖, may be written,

$$y_0 = (e + \Delta)\left(1 + \frac{3}{2}\frac{P}{P_E}\right)\P$$

and for practical purposes,

$$f = \frac{P_E}{A}\left\{1 + 1.3\,\frac{c}{r^2}\,(e + \Delta)\right\}**$$

He considers that this is not only legitimate, but is one of the simplest methods of dealing with the problem. Even if P were accidentally increased to $\frac{P_E}{2}$, there is no undue increase in the stress. With direction-fixed ends, the curves are still more nearly straight lines.††

However, for the many who prefer a formula which holds over the complete range of $\frac{l}{r}$, that of Professor Hickerson has the advantage of a rational

* Clark & Standfield, London, England.
† Received by the Secretary, August 29, 1928.
‡ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1436.
§ *Transactions*, Am. Soc. C. E., Vol. XLV (1901), p. 435.
‖ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1438.
¶ See, "Columns," Lond, 1921, p. 43 and Fig. 5.
** *Loc. cit.*, p. 44 and Equation (94).
†† *Loc. cit.*, Fig. 15.

basis, and in its simplified form is easy to apply. If one might be permitted to break a theoretical lance with him, exception might be taken to the treatment of fixed-ended columns, in that a fixed-ended column cannot be eccentrically loaded except in the sense that direction-fixing implies a negative eccentricity. It is admitted, however, that the "free-length" method is a very common one, and if discreetly applied no serious practical error results.

C. N. Ross,* Esq. (by letter).†—In his "Conclusions",‡ the author states that,

"The proposed formula has two distinct advantages as compared with the so-called secant formula: (1) It is directly solvable, whereas the secant formula can be solved only by trial and error; and (2) it is more rational, since the secant formula assumes the effects of initial curvature and eccentricity of loading as identical."

With regard to Advantage (1), the secant formula can be solved directly by substituting an approximation for the secant and solving the resulting quadratic equation for $\frac{P}{A}$,§ with the following result:

$$\sec \frac{l}{2\,r}\sqrt{\frac{P}{A\,E}} = \frac{Q + 0.26\,P}{Q - P} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (37)$$

in which, $Q = \frac{\pi^2\,E\,I}{l^2}$. This approximation is correct to 0.5 per cent. However, the solution of the secant formula by trial and error is quicker than this, and is also very much quicker than the solution of Equation (18)‖ given by the author.

With regard to Advantage (2), Equation (18) is more rational than the secant formula provided the end eccentricity of loading, and the initial deflection due to the bent shape of the column are known, but as far as the ordinary column is concerned, these quantities only can be guessed. The writer, therefore, prefers the secant formula which assumes all the eccentricity to be at the ends of the column, as it is simple and more convenient in use.

In applying Equation (18), the author assumes that $e = \frac{0.1\,r^2}{c}$ and that $\frac{\Delta\,c}{r^2} = 0.0015\,\frac{l}{r}$, or $\Delta = \frac{0.0015\,l^2}{c}$; that is, e and Δ vary as $\frac{r^2}{c}$ and $\frac{l^2}{c}$, respectively.

The ratio, $\frac{c}{r}$, varies greatly with different columns, the limiting values for average columns being from about 1.25 to 2.25. Therefore, according to Equation (18), e and Δ are not constant functions of the depth and the length of the columns.

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* Lecturer in Civ. Eng., Univ. of Queensland, Brisbane, Queensland, Australia.

† Received by the Secretary, October 2, 1928.

‡ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1446.

§ Approximation is given on p. 294 of the "Strength of Materials," by John Case, Lond., Edward Arnold & Co.

‖ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1440.

Suppose $\frac{c}{r} = 1.75$ and that $d = 2\,c$ is the depth of the column in the plane of bending, then,

$$e = \frac{0.1\,r^2}{c} = 0.057\,r = 0.0285\,d = \frac{d}{35}$$

and,

$$\Delta = \frac{0.0015\,l\,r}{c} = 0.000857\,l = \frac{l}{1\,166}$$

that is, the total eccentricity $= \frac{d}{35} + \frac{l}{1\,166}$. If a different ratio for $\frac{c}{r}$ had been taken, a different result would have been obtained, and yet it seems reasonable to assume that e varies with d, and that Δ varies with l.

In a paper entitled "Column Eccentricity",* the writer has given the value for the total eccentricity, $e + \Delta$ as $\frac{d}{50} + \frac{l}{500}$. A curvature in a column with a slenderness ratio of $\frac{l}{500}$ could hardly be detected by the eye, and, therefore, it is probable that many columns in practice are as crooked as this, but probably none is worse.

Using the secant formula with a total eccentricity of $\frac{d}{50} + \frac{l}{500}$ and different ratios for $\frac{c}{r}$, the writer obtained curves of $\frac{P}{A}$ *vs.* $\frac{l}{r}$, which are close approximations to straight lines, and to many of the straight-line formulas in general use.†

One curve, called the "Stability Curve", is of the form:

$$\frac{P}{A} = \frac{1}{2}\,\frac{\pi^2\,E\,r^2}{l^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (38)$$

which gives one-half the Euler stress. The stress given by this curve is used when it is lower than that given by the secant formula; the column then has a factor of safety of two against buckling.

A curve for nickel steel based on these studies‡ will show that the advantage of a high grade steel over ordinary structural steel becomes rapidly less beyond $\frac{l}{r} = 110$, and ceases altogether at $\frac{l}{r} = 145$.

The author also mentions§ certain ideal end conditions as given in textbooks, and points out that no practical column "is either perfectly 'direction-free' or perfectly 'direction-fixed' ".

The writer considers all cases, no matter what the end conditions, as eccentrically loaded hinged-end columns, in which the eccentricity is such that Pe is equal to the fixing moment or couple which is acting at the end of the

* *Transactions*, Institution of Engrs., Australia, Vol. IV, 1923.

† The diagrams are given in Tables I, II, and III, and the curves on Plate B, of "Column Eccentricity," pp. 4 and 5.

‡ "Column Eccentricity," Plate B, p. 5.

§ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1446.

column. This makes it necessary to consider columns with any end eccentricities whatever, of which the secant formula is only the particular case of equal eccentricities of the same sign. To explain this statement the writer repeats a part of a previous paper on this subject.* The following notation will be used:

l = length of a pin-ended column.

l' = virtual length of a column.†

Q = Euler's value $= \dfrac{\pi^2 E I}{l^2}$.

k = radius of gyration of the cross-section.

$q = \dfrac{Q}{A} = \dfrac{\pi^2 E k^2}{l^2}$.

$p = \dfrac{P}{A}$.

e_1 and e_2 = eccentricities of loading, in the same plane, at the two ends of a column, of which e_1 is the greater. They will have the same sign when in the same direction from the axis of the column, and opposite signs when in opposite directions from the axis.

y_1 and y_2 = distances of the extreme fibers from the neutral axis.

$d = y_1 + y_2$ = width of a section.

$\dfrac{a}{2}$ and $\dfrac{b}{2}$ = distances from the two ends to the point of maximum deflection of a deflected column.

h = the maximum ordinate of a deflected column.

M_1 and M_2 = couples acting at the two ends of a column.

m = the fraction that the secondary stress is of the primary stress, that is, secondary stress $= m\ p$.

As the ratio, $\dfrac{p}{q}$, becomes smaller, h will also become smaller until it becomes equal to e_1, when the bent column will be as shown in Fig. 8(a) and 8(b).

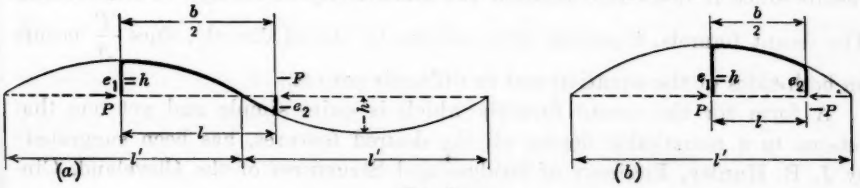


FIG. 8.

In this case, $a = 0$ and,

$$\frac{e_2}{e_1} = \cos\left(\pi\sqrt{\frac{p}{q}}\right) \qquad \text{.....(39)}$$

* "Equivalent Eccentricities Due to Secondary Stresses," by C. N. Ross, *Transactions*, The Institution of Engrs., Australia, Vol. VIII (1927), p. 8.

† "A Practical Column Diagram with Proof," by R. W. H. Hawken, *Minutes of Proceedings*, Inst. C. E., Vol. CCV, Pt. I.

Equation (39) gives the ratio, $\frac{p}{q}$, for a given ratio, $\frac{e_2}{e_1}$, at which $e_1 = h$. This will be called the critical ratio.

At the critical ratio the maximum moment is at the end of the column and is equal to $P e_1$.

When $\frac{p}{q}$ is less than the critical ratio, the maximum ordinate (h) of the full cosine curve is outside the length of the given column, and the maximum moment is at the end of the column and is equal to $P e_1$.

TABLE 2.

$\frac{e_2}{e_1}$.	Critical $\frac{p}{q}$.	$\frac{e_2}{e_1}$.	Critical $\frac{p}{q}$.
1.00	0.000	−0.60	0.497
0.75	0.053	−0.75	0.593
0.50	0.111	−0.80	0.632
0.25	0.176	−0.90	0.733
0.00	0.250	−0.95	0.808
−0.25	0.337	−1.00	1.000
−0.50	0.444		

Therefore when $\frac{p}{q}$ is equal to or less than the critical ratio, the column deflection, within the length of the actual column, is less than the end eccentricity, and the column can be designed for combined bending and direct stress without using any column formula. Critical ratios, calculated by Equation (39), are given in Table 2.

K. L. De Blois,* Jun. Am. Soc. C. E. (by letter).†—The column formulas in general use seem to have been adopted primarily on account of their simplicity and the fact that they fit, with some accuracy, the results of meager tests.

The writer believes that a formula of the secant type would give the best results since it takes into account the eccentricity and shape of the column. The secant formula, Equation (27),‡ cannot be solved directly, since $\frac{P}{A}$ occurs on both sides of the equation and in different powers.

A form for the secant formula which is quite simple and yet one that retains to a remarkable degree all the desired features, has been suggested§ by J. B. Hunley, Engineer of Bridges and Structures of the Cleveland, Cincinnati, Chicago and St. Louis Railway Company.

Mr. Hunley computed $p = \frac{P}{A}$ for sixteen columns with different shapes and make-up by the author's Equation (27), using the trial and error method.

* Asst. Engr., C. C. C. & St. L. Ry., Cincinnati, Ohio.

† Received by the Secretary, October 4, 1928.

‡ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1446.

§ "A Simplified Column Formula of the Secant Type", *Proceedings*, Am. Ry. Eng. Assoc., Vol. 29 (1928), p. 1191.

The eccentricity used is that suggested by Mr. E. H. Salmon,* that is, for crookedness of fabrication and variation in material over the section, $\frac{l}{750} + \frac{h}{40}$; for average eccentric application of the load, $\frac{l}{1\,000} + \frac{h}{40} + \frac{h}{160}$; and the assumed total eccentricity is the sum of these, or $e = 0.00233\,l + 0.05625\,h$, in which e = eccentricity, in inches; l = length of columns, in inches; and h = distance, in inches, between the centers of gravity of all the elements of the column section on either side of the vertical axis.

Values of A, I, r, h, and $\frac{e}{r}$ were computed for each column about each axis, and curves showing values of e, $\frac{e}{r}$ and $\sec\left(\frac{l}{2\,r}\sqrt{\frac{p}{E}}\right)$ were drawn for values of $\frac{l}{r}$ up to 300 for each column.

It was found that the term in the secant formula, $\sec\left(\frac{l}{2\,r}\sqrt{\frac{p}{E}}\right)$, is near enough to a parabola to be expressed by the equation:

$$1 + \frac{\left(\frac{l}{r}\right)^2}{X\left(\frac{c}{r}\right)} \qquad (40)$$

or, letting $\frac{l}{r} = k$,

$$\sec\left(\frac{k}{2}\sqrt{\frac{p}{E}}\right) = 1 + \frac{k^2}{X\left(\frac{c}{r}\right)} \qquad (41)$$

when X is a constant.

The formula then develops into the following type:

$$p = \frac{f}{1 + \frac{e}{r}\left(\frac{k^2}{X} + \frac{c}{r}\right)} \qquad (42)$$

For varying values of k the value of $\frac{e}{r}$ is quite uniform for the sixteen different columns and a mean value of $0.00233\,k + 0.1$ can be assumed for $\frac{e}{r}$. This avoids a rather tedious computation of h.

The value, $\frac{c}{r}$, between $k = 20$ and $k = 60$, has a marked effect on the value of $\frac{P}{A}$, and it is strange that this factor has been ignored in the present-day column formulas. The value, $\frac{c}{r}$, approaches 1.0 as a minimum. A cylindrical cross-section is the nearest approach to the ideal, but, in the ordinary sections $\frac{c}{r}$ varies from 1.15 for the most economical to 2.50 for the least economical.

* "Columns," by E. H. Salmon, Lond., 1921, p. 42.

It has generally been assumed that, if the column section were such that the radius of gyration were the same about either axis, a column of given length would have the same strength about either axis, but the application of the secant formula shows that this is not true, unless the value of $\frac{c}{r}$ is the same about both axes.

The variation of $\frac{c}{r}$ between 1.50 and 2.50 affects the value of $\frac{P}{A}$ as much as a variation of k from 40 to 60 or 60 to 80. To ignore this important fact and continue to use some formula based on the value of k only, merely for the sake of "simplicity", or "ease of application" seems inexcusable. In Equation (18)* the author uses the ratio, $\frac{c}{r}$, in the term, $(\Delta + e)\frac{c}{r^2}$, corresponding to the $\frac{e\,c}{r^2}$ used in the secant formula. However, in the simplified form (Equation (19)†), a value of $(\Delta + e)\left(\frac{c}{r^2}\right)$ is assumed, which is presumably to be used on all columns regardless of the $\frac{c}{r}$ ratio. Thus, the author's formula contains only the variable, $k = \frac{l}{r}$, and, in the writer's opinion, it is but little improvement over the usual column formulas.

The formula suggested by Mr. Hunley has three desirable features, namely, that (1) it is easy to apply; (2) it contains the factor, $\frac{c}{r}$; and (3) the constant, X, is such that the formula follows the secant formula remarkably close up to a slenderness ratio of $k = 200$. The constant, X, will vary with the e assumed, the allowable stress, f, and the assumed end conditions.

Considering a column with pivoted ends: When $f = 20\,000$ lb. per sq. in. and $e = 0.00233\,l + 0.05625\,h$, $X = 9\,000$ and Equation (42) becomes,

$$p = \frac{20\,000}{1 + \frac{e}{r}\left(\frac{k^2}{9\,000} + \frac{c}{r}\right)} \qquad (43)$$

Using a probable minimum value of $e = \frac{l}{750} = 0.00133\,l$, Equation (43) becomes,

$$p = \frac{20\,000}{1 + \frac{e}{r}\left(\frac{k^2}{3\,500} + \frac{c}{r}\right)} \qquad (44)$$

From the derivation of the formula, it is seen that p does not vary directly as f; that is, the value of p, when f is assumed as 36 000 lb. per sq. in., is not 2¼ times the value of p when f is assumed as 16 000 lb. per sq. in. This is evident since an increase in p, Fig. 1,‡ means an increase in y_t,§ in $(\Delta + e)$,

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1440.
† *Loc. cit.*, p. 1442.
‡ *Loc. cit.*, p. 1436.
§ *Loc. cit.*, pp. 1438–1439.

Equation (18), and in e in the secant formula, with the result that the increase in p is less than the proportional increase in f for corresponding slenderness ratios.

Thus, if the tension members of a structure were designed for a certain loading and a unit stress of 16 000 lb. per sq. in., they would all become stressed 36 000 lb. per sq. in. if the load were increased 2¼ times; while, if the compression member were designed for the same load and by Equation (19) or Equation (21),* or by the usual column formulas, and the load were then increased 2¼ times, the unit stress in the compression members would exceed 36 000 lb. per sq. in. considerably.

In other words, while tension members in a structure may have a factor of safety of 2¼, using Equation (18) as an example, the compression members will have a factor of safety that is considerably less. To have a structure, which would be stressed uniformly to 36 000 lb. per sq. in. in all its members under an increased load, for the compression members, designers should start with a formula in which f has a value of 36 000. Then, if it is desired to use a designing stress of 16 000 lb. per sq. in., the values of p obtained are divided by 2¼. While the elastic limit of column material may be 36 000 lb. per sq. in., the useful limit in railroad bridge work is 26 000 lb. per sq. in.; that is, when that limit is reached under increased loading, the structure is usually considered ready for renewal. In the paper by Mr. Hunley, previously mentioned, the values of p were computed for the sixteen columns about their limiting axis, using the secant formula (Equation (27)†), assuming $f = 26\,000$ lb. per sq. in. and $e = 0.00233\,l + 0.05625\,h$.

The modified secant formula was found to be

$$p = \frac{26\,000}{1 + \frac{e}{r}\left(\frac{k^2}{6\,400} + \frac{c}{r}\right)} \qquad \text{.....(45)‡}$$

If a basic designing stress of 20 000 were selected, the designing formula would be:

$$p = \frac{20\,000}{1 + \frac{e}{r}\left(\frac{k^2}{6\,400} + \frac{c}{r}\right)} \qquad \text{.....(46)§}$$

Formula (46) will produce slightly heavier sections than Formula (43), but, with an increase of 30% over the designing load, the structure will be uniformly stressed to 26 000 lb. per sq. in. under Formula (46), while under Formula (43), the compression members would be stressed to 26 000 lb. per sq. in. before the tension members reached that limit.

EDWARD GODFREY,‖ M. AM. SOC. C. E. (by letter).¶—The author's first attack on the column question is, in the writer's opinion, the truly rational

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1444.

† *Loc. cit.*, p. 1446.

‡ "A Simplified Column Formula of the Secant Type", by J. B. Hunley, *Proceedings*, Am. Ry. Eng. Assoc., Vol. 29 (1928), p. 1194, Equation (5).

§ *Loc. cit.*, p. 1194, Equation (6).

‖ Structural Engr., Pittsburgh, Pa.

¶ Received by the Secretary, October 9, 1928.

method of reaching a solution of this problem. It is rational in the sense of being logical and also in the sense of being mathematically sound. However, the writer would not follow him beyond Equation (18).* Of course this equation is cumbersome and totally unsuited for practical use, but for the reason that it contains the practical elements that gauge the strength or make for the weakness of commercial steelwork, it gives reliable values for the strength of ordinary structural work. To use Equation (18) for the purpose of deriving a practical column formula requires some simplification that can be readily applied and can be considered appropriate to a wide range of structural columns.

Professor Hickerson has assumed eccentricity in a column of two types: One is an application of the load off the center line of the column; the other is an initial bow. With both these eccentricities relatively small, it makes little difference whether the whole eccentricity is in the bow or whether it is divided between the bow and the off-center application of the load. One angle of the problem is to find an assumed eccentricity of application of the load that will be about what might be expected in practice. If an eccentricity of this kind that does not complicate the equation can be used, it will help in finding a formula suitable for use in designing.

In inspection of steelwork certain tolerances are allowed. Absolute straightness, for instance, is not commercially attainable. A variation from a straight line of not much more than one-quarter of 1% is considered commercially straight. Anything less than this can scarcely be seen without laying a line on the piece, and a greater bow is usually not difficult to detect. If then one-third of 1% is assumed, in order to allow for a small eccentricity in the application of the load, the value of $\frac{1}{3\,0\,0}$ could be substituted for $(\Delta + e)$ in Equation (18).

Another substitution that would simplify this equation and make it of general application is to use a function of r in place of the value, c, the distance to the extreme fiber in the cross-section. In a built section, c is about $1\frac{1}{4}\ r$, and, in a rectangular section, it is about $1\frac{3}{4}\ r$. Using $1\frac{1}{2}\ r$ as a mean and substituting this for c, Equation (18) reduces to such a form that a locus of the curve of allowed unit stresses can be plotted by merely supplying an extreme fiber stress, f. (It is to be noted that Professor Hickerson uses the smaller value of c.† The larger value would give the higher unit stress, and it is, therefore, the critical value. It is almost exactly $1\frac{1}{2}$ times r.)

The equation is still too cumbersome to use in practice, but the locus is a remarkable one. This is illustrated in Fig. 9 for $f = 16\,000$ lb. per sq. in. The locus coincides with that of the commonly used formula, $16\,000 - 70\,\frac{l}{r}$, up to a slenderness ratio of 120. Then it curves up toward the Euler load. This is as it should be, for it is in agreement with tests as well as theory.

Objection is often made to a straight-line formula because it has no application to slender columns, but every one who uses the straight-line formula understands this limitation. This objection, therefore, can have no

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1440.
† *Loc. cit.*, p. 1442.

force. Slender columns should be designed by a formula on the order of the Euler formula.

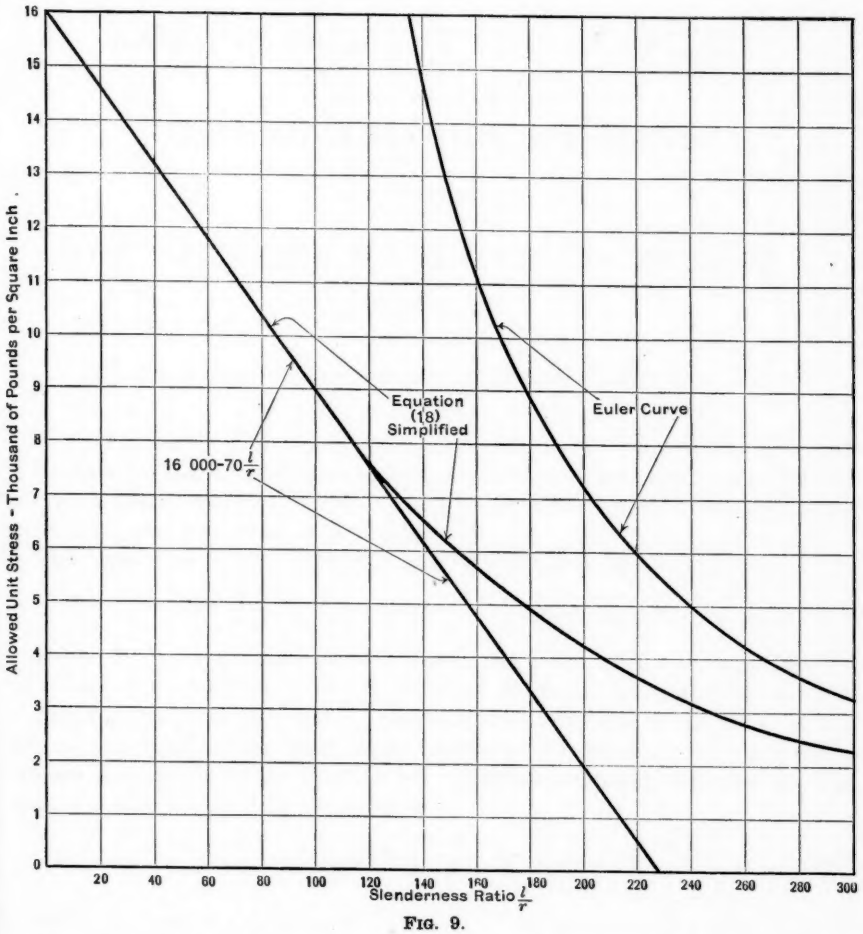
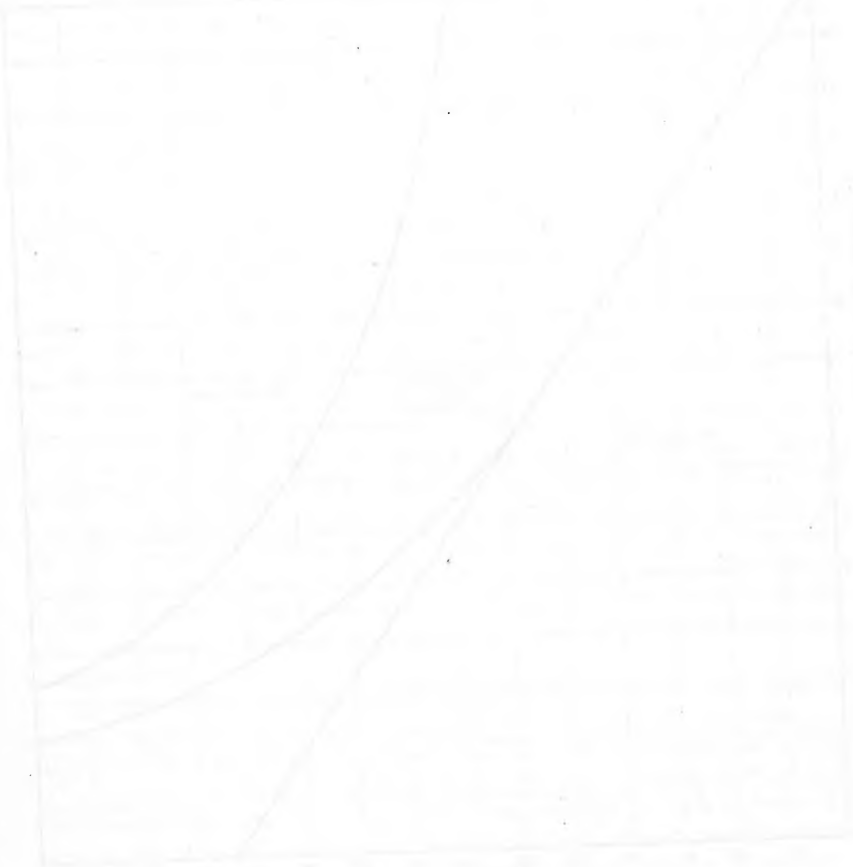


FIG. 9.

The straight-line formula is shown by the foregoing to have a rational basis that no other column formula for shorter columns possesses. Limiting its application to structurally permissible columns, the straight-line locus results from an absolutely rigid mathematical analysis of column action with but one simple and eminently logical assumption, namely, an original bow of $\frac{1}{3\,0\,0}$ of the length of the column.

The writer has emphasized this in the past* and has derived a formula giving this identical locus. Therefore, in spite of all the contempt which mathematicians have heaped on the straight-line formula, it is the one mathematically correct formula for structurally permissible columns.

* *Railroad Age Gazette*, July 2, 1909; see, also, "Steel Designing," by Edward Godfrey, M. Am. Soc. C. E.



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THE STIFFNESS OF SUSPENSION BRIDGES

Discussion*

By Messrs. E. Steuermann and George C. Priester.

E. Steuermann,† Esq. (by letter).‡—The solution of the problem presented by Professor Timoshenko§ is of universal significance and can be applied not only when the moment of inertia of the stiffening truss is constant within the entire span, but also when it is variable.

The author's Equation (4)‖ may also be written in the form:

$$E\,I\,\frac{d^2\,\eta}{d\,x^2} - H_w\,(1 \pm \beta)\,\eta = -\,M_x + \beta\,H_w\,y \ldots\ldots\ldots\ldots (24)$$

in which, M_x is the bending moment due to the action of the external load on the truss. This formula is equally effective when the value of I is variable.

Suppose, for example, that I_1, the moment of inertia of the truss at the ends, is less than I_0, the moment of inertia at the center. This is quite a rational assumption if the truss is not continuous through the towers. The value of I may be found by the equation:

$$I = I_0 \sin\left(\frac{m\,\pi\,x}{l} + \alpha\right) \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

in which, $\alpha = \sin^{-1}\left(\frac{I_1}{I_0}\right)$ and $m = 1 - \frac{2\,\alpha}{\pi}$. When $I_1 = \frac{I_0}{2}$, then $\alpha = \frac{\pi}{6}$ and $m = \frac{2}{3}$.

Equation (25) imposes a definite and, in many cases, an admissible restriction on the manner in which the moment of inertia, I, shall vary, but is considered only for a specific case. The method of calculation that follows is equally applicable for the general case:

$$I = I_0\,f\,(x) \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

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* Discussion of the paper by S. Timoshenko, Esq., continued from October, 1928, *Proceedings*.

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‡ Received by the Secretary, September 12, 1928.

§ *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1464.

‖ *Loc. cit.*, p. 1466.

Expanding the right side of Equation (24) into the series of Fourier:

$$-M_x + \beta H_w y = -\left(b_1 \sin\frac{\pi x}{l} + b_2 \sin\frac{2\pi x}{l} + \ldots + b_n \sin\frac{n\pi x}{l}\right) \ldots (27)$$

in which,

$$b_n = \frac{2}{l}\int_0^l (M_x - \beta H_w y)\, d x \ldots (28)$$

The integral, η, may be presented in the form of a series, as follows:

$$\eta = a_1 \sin\frac{\pi x}{l} + a_2 \sin\frac{2\pi x}{l} + \ldots + a_n \sin\frac{n\pi x}{l} + \ldots = \sum_1^\infty a_n \sin\frac{n\pi x}{l} \ldots (29)$$

Substituting in Equation (24), the values found by Equations (27) and (29), and changing signs:

$$\frac{\pi^2 E I_0}{l^2} \sin\left(\frac{m\pi x}{l} + \alpha\right) \sum_1^\infty n^2 a_n \sin\frac{n\pi x}{l} + H_w(1+\beta)\sum_1^\infty a_n \sin\frac{n\pi x}{l} = \sum_1^\infty b_n \sin\frac{n\pi x}{l} \ldots (30)$$

To determine the coefficients, a_n, multiply both sides of Equation (30) by $\sin\frac{\kappa\pi x}{l}$ (in which, $\kappa = 1, 2, 3 \ldots n$), and integrate between the limits 0 and l, then,

$$\frac{\pi^2 E I_0}{l^2}\sum_1^\infty n^2 a_n \int_0^l \sin\left(\frac{m\pi x}{l} + \alpha\right)\sin\frac{m\pi x}{l}\sin\frac{\kappa\pi x}{l}\, d x + H_w(1+\beta) \sum_1^\infty a_n \int_0^l \sin\frac{n\pi x}{l}\sin\frac{\kappa\pi x}{l}\, d x = \sum_1^\infty b_n \int_0^l \sin\frac{n\pi x}{l}\sin\frac{\kappa\pi x}{l}\, d x \ldots (31)$$

By the known formulas of integral calculus:

$$\int_0^l \sin\left(\frac{m\pi x}{l} + \alpha\right)\sin\frac{n\pi x}{l}\sin\frac{\kappa\pi x}{l}\, d x = \frac{2[(-1)^{n+\kappa+1} - 1] m l n \kappa}{\pi[(n-\kappa)^2 - m^2][(n+\kappa)^2 - m^2]} \ldots (32)$$

Substituting Equation (32) in Equation (31) and transposing the terms:

$$a_\kappa + \frac{4\pi E I_0 m \cos\alpha}{H_w l^2 (1+\beta)} \sum_1^\infty \frac{[(-1)^{n+\kappa+1} - 1]\kappa n^3 a_n}{[(n-\kappa)^2 - m^2][(n+\kappa)^2 - m^2]} = \frac{b_\kappa}{H_w(1+\beta)} \ldots (33)^*$$

in which, $\kappa = 1, 2, 3, \ldots n$. Let,

$$\mu = \frac{4\pi E I_0 m \cos\alpha}{H_w l^2 (1+\beta)} \ldots (34)$$

$$N_{\kappa n} = \frac{[(-1)^{n+\kappa+1} - 1]\kappa n^3}{[(n+\kappa)^2 - m^2][(n-\kappa)^2 - m^2]} \ldots (35)$$

and,

$$C_\kappa = \frac{b_\kappa}{H_w(1+\beta)} \ldots (36)$$

Then, Equation (33) becomes:

$$a_\kappa + \mu \sum_1^\infty N_{\kappa n} a_n = C_\kappa \ldots (37)$$

* When $\alpha = 0$, $m = 1$, and $n = \kappa = \pm 1$, the right side of Equation (32) assumes the indeterminate form $\frac{0}{0}$, the limiting value of which is 0.

If Equation (29) is restricted to a definite number of terms, that is, γ-terms, or enough to express the value of η accurately, Equation (37) will also include the same definite number of terms, such that $\kappa = 1, 2, 3, \ldots . \gamma$.

Solving Equation (37) within these definite limits will express a_1, a_2, a_3 $\ldots$ a_γ, as well as η as functions of β. The author derives Equation (18)* for use in determining the value of β and the same equation can be used in the present case. The remainder of the solution follows exactly the method described by the author for trusses of constant section.

The solution of Equation (37) is simplified due to the fact that it may be separated into two independent parts, one containing the term, a_κ, for even values of κ and the other for odd values of κ. This is made evident by the fact that $N_{\kappa n} = 0$, when κ is even and n is odd, or *vice versa*.

If the value of I is determined by Equation (26), the integrals,

$$\int_0^l f(x) \sin \frac{n \pi x}{l} \sin \frac{\kappa \pi x}{l} \, d x$$

(in which, κ and $n = 1, 2, 3, \ldots n$), would appear in Equation (33). In many cases, for instance, when $f(x)$ is a polynomial or an exponential function, it is possible to solve them exactly, but generally they can be determined easily by some approximate method.

The theory herein presented may be applied to the numerical example given by the author,† except that the moment of inertia diminishes, according to Equation (25), to one-half the given value at the support.

First, compute the coefficients, b_n. In the given case it will be easier to use, not Equation (28), but the known equation:

$$\frac{d^2 M}{d x^2} = - q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (38)$$

in which, M is the bending moment of the truss and q is the load. In this specific example, $q = p - \beta w$ when $0 \leq x \leq \frac{l}{4}$ and $q = - \beta w$ when $\frac{l}{4} \leq x \leq l$.

Expanding q into a trigonometric series and integrating twice (see Equation (38)):

$$M_x - \beta H_w y = \sum_1^\infty \frac{2 l^2 \left\{ p \left(1 - \cos \frac{n \pi}{4}\right) - \beta w [1 - (-1)^n] \right\} \left(\sin \frac{n \pi x}{l}\right)}{\pi^3 n^3} \ldots (39)$$

Then, from Equation (36):

$$C_n = \frac{2 l^2 \left\{ p \left(1 - \cos \frac{n \pi}{4}\right) - \beta w [1 - (-1)^n] \right\}}{H_w (1 + \beta) \pi^3 n^3} \ldots\ldots (40)$$

The author has demonstrated that, in order to determine η, it will be sufficient to restrict the expansion of Equation (29) to four terms so that in Equation (37), the value of γ is 4. It is almost evident from the mechanical

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1473.
† *Loc. cit.*, p. 1467.

calculations that the deflection curve can be represented in the form of four sinusoids. Using the data suggested by the author,* Equation (37) becomes:

$$\left.\begin{aligned} a_1 + \mu\left(\frac{81}{64}a_1 - \frac{27.81}{16.140}a_3\right) &= C_1 \\ a_2 + \mu\left(-\frac{162}{35}a_2 - \frac{81}{40}a_4\right) &= C_2 \\ a_3 + \mu\left(-\frac{243}{16.140}a_1 + \frac{81^2}{640}a_3\right) &= C_3 \\ a_4 + \mu\left(-\frac{81}{100} + \frac{32.81}{143}a_4\right) &= C_4 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (41)$$

From this point the solution is not difficult and, therefore, does not need to be presented. Its application to the particular case presented by the author,† namely, to find the corresponding values of p when $\beta = 0.2$, is as follows: Calculating the value of p from Equation (34), the values of a in Equation (41) can be easily found in terms, C, by making the proper substitutions and solving simultaneous equations. The results are:

$$\left.\begin{aligned} a_1 &= 0.6944\ C_1 + 0.0517\ C_3 \\ a_2 &= 0.3842\ C_2 + 0.0371\ C_4 \\ a_3 &= 0.0057\ C_1 + 0.2184\ C_3 \\ a_4 &= 0.0093\ C_2 + 0.1370\ C_4 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (42)$$

In order to make the remaining calculations shorter, it is best to introduce the quantities:

$$\kappa = \frac{2\ l^2}{H_w\ (1 + \beta)\ \pi^3} = 21.99 \quad \ldots\ldots\ldots\ldots\ldots (43)$$

$$C_n = \kappa\ C_n' \quad \ldots\ldots\ldots\ldots\ldots (44)$$

$$a_n = \kappa\ a_n' \quad \ldots\ldots\ldots\ldots\ldots (45)$$

Then, by making proper substitutions in Equation (40) values of C are determined as follows:

$$\left.\begin{aligned} C_1' &= \frac{0.2929\ p - 2\ \beta\ w}{1} \\ C_2' &= \frac{p}{8} \\ C_3' &= \frac{1.7071\ p - 2\ \beta\ w}{27} \\ C_4' &= \frac{p}{32} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (46)$$

Consequently, according to Equation (42):

$$\left.\begin{aligned} a_1' &= 0\ 2067\ p - 1\ 621 \\ a_2' &= 0.0492\ p \\ a_3' &= 0.0155\ p - 32.126 \\ a_4' &= 0.0054\ p \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (47)$$

In the author's Equation (18), substitute the values of a_n found by Equations (45) and (47) and also the other numerical values given; then the value

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1467.
† *Loc. cit.*, p. 1474.

of p will be found equal to 7 937 lb. per lin. ft. = 661.5 lb. per lin. in. Beyond this point the solution is exactly as given by the author.

As a second example, consider the same bridge, assuming that $I_1 = 0$ and that $\beta = 0.2$, as before. In Equation (25), since $\alpha = 0$ and $m = 1$:

$$I = I_0 \sin \frac{\pi x}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (48)$$

Then, following the same procedure as in Equation (46):

$$\left.\begin{aligned} C_1 &= 1.404\ a_1 - 0.727\ a_3 \\ C_2 &= 2.294\ a_2 - 1.479\ a_4 \\ C_3 &= -0.081\ a_1 + 3.850\ a_3 \\ C_4 &= -0.370\ a_2 + 5.930\ a_4 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (49)$$

and,

$$\left.\begin{aligned} a_1' &= 0.221\ p - 1\,692 \\ a_2' &= 0.0653\ p \\ a_3' &= 0.021\ p - 58.7 \\ a_4' &= 0.0098\ p \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (50)$$

The author's Equation (18) will then become:

$$0.266 \times 10^{-5}\ p^2 + 0.199\ p - 1\,689.4 = 0$$

$$p = 7\,700 \text{ lb. per lin. ft.} = 642 \text{ lb. per lin. in.}$$

Comparing these values of p (661.5 and 642) with those determined by the author* for a truss with a constant rigidity ($p = 671$ lb. per lin. in.), will show that the magnitude of the load necessary to cause a definite increase, H, in the stress, H_w, will diminish very slowly with a decrease in the rigidity of the truss. When the moment at the support is reduced one-half, the value of p decreases only 9.5 lb. per lin. in., whereas when the moment at the support is zero, the decrease is 29 lb. per lin. in. (A somewhat greater decrease would be obtained if a less favorable curve than that described by Equation (25) were assumed.) In other words, the horizontal component as well as the total tension in the cable increases under the action of a given temporary load at a rate considerably slower than the corresponding decrease in the rigidity of the truss. This result may interest the bridge engineer, because it will, perhaps, allow a more rational construction of the stiffening truss.

GEORGE C. PRIESTER,† ESQ. (by letter).‡—The application of a trigonometric series to a deflection problem is so advantageously presented in this paper that it is desirable to discuss the problem of the stiffened suspension bridge in more detail.

The writer presents an extension of this problem in the following studies: (*a*) The relation between the additional horizontal component of cable stress and live load; (*b*) the application of the live load in two increments; (*c*) the solution of a problem when the cable is attached to the towers; and (*d*) the effect of a concentrated load on the span. The notations used are the same as those in the paper.

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‡ Received by the Secretary, September 21, 1928.

The Relation Between β and p.—Since p represents the live load per unit length over a part or all of the truss and $\beta = \frac{H}{H_w}$, the relation between these two values will be used in terms of numerical quantities. For this problem the relation between p and β will be investigated for a three-span suspension bridge with the cable free to move over the towers. It will be assumed that the live load covers the main span from $x = 0$ to $x = \frac{l}{4}$; that there is no live load on the side spans; and that the temperature is 55° Fahr. above normal. The other numerical data for this problem are those of the Manhattan Bridge.*

In order to solve the numerical computations it is desirable to assume values for β in Equation (22)† and compute p. This will be done in various ways: First, by assuming the load and temperature to act simultaneously, that is, by using the complete equation; second, by assuming the same values for β and the temperature to be normal; and third and fourth, to carry out the same computations by omitting the terms involving the square of the coefficients, a_n and b_n, for the first and second case. The values of p obtained by the first and second method will be called p (exact) in contrast with those obtained by the third and fourth method in which they will be called p (approximate). The p (approximate) values correspond to those obtained by the deflection method, since the original assumptions in the development of the equations for these two cases are identical. The results for these conditions are given in Table 1.

TABLE 1.—VARIATION OF p AND β. WITH AND WITHOUT TEMPERATURE (THREE SPANS).

β.	p (exact) $t = 55°$ Fahr.	p (exact) without allowing for temperature.	Difference.	p (approximate) $t = 55°$ Fahr.	p (approximate) without allowing for temperature.	Difference.
0.05	277.1	196.1	81.0	280.0	197.2	82.8
0.10	474.3	391.8	82.5	481.2	395.7	85.8
0.20	866.5	781.5	85.0	887.5	797.0	90.5
0.40	1 641.0	1 552.0	89.0	1 717.0	1 616.0	101.0

It will be noted that the values in the "Difference" columns increase with an increase in β. This is to be expected since the term in Equation (22) which takes into account the effect of temperature is of the form,

$$H_w \left(1 + \frac{\beta}{2}\right) \omega\, t\, L_t$$

and an increase in β will increase the effect of a given temperature.

It should be noted that there is a slight deviation from a linear proportionality between p and β. Since this deviation is small it is possible to assume a linear relation for small increments of β.

* *Proceedings*, Am. Soc. C. E., May, 1928, Papers and Discussions, p. 1467.
† *Loc. cit.*, p. 1477.

The Live Load Applied in Two Increments.—In the development of Equation (22) the average load, $w + \frac{q}{2}$, was assumed to be acting through the distance, η, in calculating the work done. A numerical example will show that this assumption may be used. Since a simple problem will suffice, it will be assumed that the suspension bridge consists of only one span and that the cables are fastened rigidly at the towers. The data of the main span of the Manhattan Bridge will be used. For numerical computation two-increment loading is chosen. The live load, q, acting on the cable will be divided into two parts. In the first increment the average load acting on the cable will be $w + \frac{q_1}{2}$, and, in the second increment, $w + q_1 + \frac{q_2}{2}$. The deflection of the truss for the first increment of loading will be designated by η_1 and that for the second increment by η_2. Also, let H_1 equal the additional horizontal component of cable stress due to the first increment; and H_2, that for the second increment of loading. Then, $\beta_1 = \frac{H_1}{H_w}$ and $\beta_2 = \frac{H_2}{H_w + H_1}$.

For the first increment of loading the equation for determining H_1 is:*

$$\frac{{H_w}^2 L}{A E} \beta_1 \left(1 + \frac{\beta_1}{2}\right) = \frac{2 w}{\pi} \left(1 + \frac{\beta_1}{2}\right) \left(a_1 + \frac{1}{3} a_3 + \frac{1}{5} a_5 + \ldots\ldots\right) + \frac{\pi^2 H_w}{4 l} (1 + \beta_1) \left({a_1}^2 + 2^2 {a_2}^2 + 3^2 {a_3}^2 + \ldots\ldots\ldots\right) \ldots\ldots\ldots (51)$$

and for the second increment of loading, the equation for determining H_2 is:

$$\frac{{H_w}^2 (1 + {\beta_1}^2) \beta_2 \left(1 + \frac{\beta_2}{2}\right) L}{A E} = \frac{2 w l}{\pi} (1 + \beta_1) \left(1 + \frac{\beta_2}{2}\right) \left(a_1' + \frac{1}{3} a_3' + \frac{1}{5} a_5' + \ldots\right) + \frac{\pi^2 H_w}{4 l} (1 + \beta_1) (3 + 2 \beta_2) \left((a_1')^2 + 2^2 (a_2')^2 + 3^2 (a_3')^2 + \ldots\right) \ldots (52)$$

in which,

$$a_n' = \frac{2 l^4}{E I \pi^5} \frac{p \left(\cos \frac{n \pi a}{l} - \cos \frac{n \pi b}{l}\right) - \beta_2 (1 + \beta_1) w (1 - \cos n \pi)}{n^5 + n^3 \alpha (1 + \beta_1) (1 + 2 \beta_2)} \ldots (53)$$

For $\beta_1 = 0.10$, the value of p from Equation (51) is 338.2 lb. per lin. in. and, for $\beta_2 = 0.10$, the value of p from Equation (52) is 368.0 lb. per lin. in. The load which will produce an additional horizontal component of cable stress corresponding to $\beta_1 + \beta_2$ will be the sum of p_1 and p_2, or 706.2 lb. per lin. in.

Since it is necessary to determine whether a single loading will produce the same effect as the two-increment loading, a single value of β (= 0.21) must be used, which is equivalent to $\beta_1 + \beta_2$. Then (Equation (51)), the value of p

* The development of the equations used in this discussion and a more detailed study of the suspension bridge are to be published as an *Engineering Research Bulletin*, Univ. of Michigan.

is 706.0 lb. per lin. in. This agrees with the value of the sum of p_1 and p_2 when the load is applied in two increments. For a second illustration of this problem assume that $\beta_1 = \beta_2 = 0.20$. When $\beta_1 = 0.20$, the value of p_1 is found to be 673.0 lb. per lin. in. by the use of Equation (51). With $\beta_2 = 0.20$ for the second increment, the value of p_2 is found to be 790.0 lb. per lin. in., by the use of Equation (52). The sum of p_1 and p_2 is 1 463.0 lb. per lin. in. The value, $\beta = 0.44$, corresponds to $\beta_1 + \beta_2 = 0.40$. From Equation (51) for $\beta = 0.44$, p is 1 461.0 lb. per lin. in. Thus, it is shown that by the use of the average load, $w + \frac{q}{2}$, a sufficiently accurate value of the cable stress is found.

An Analysis of Stress with the Cable Fixed at the Towers.—When the cable for a three-span suspension bridge is fixed at the towers, as in the case of the Delaware River Bridge, the deflection of the towers must be taken into account when a live load or a temperature change is acting on the structure. The equations necessary for the computation of the value of H for a symmetrically placed load and equal side span will be given. (Similar equations can be developed when these conditions are not symmetrical.)

Since the towers are bent by a change in the cable stress and since the stress in the cable over the side span is different from that in the main-span cable, it is necessary to have an equation for the side span, one for the main span, and one for the deflection of the towers.

Besides the notations previously given, it is necessary to use the following:

H_1 = the additional horizontal component of stress in the cable of the side spans.
δ = the deflection of the towers.
I_t = the moment of inertia of a cross-section of the tower about the axis perpendicular to the plane of bending.
h = the height of the tower.
S = the vertical component of the total cable stress.

$$\beta_1 = \frac{H_1}{H_w}$$

$$L_{1s} = \int_0^{l_1} \left(\frac{d\,s_1}{d\,x}\right)^2 d\,s_1$$

$$L_{1t} = \int_0^{l_1} \left(\frac{d\,s_1}{d\,x}\right) d\,s_1$$

The equation of equilibrium for the side span is:

$$\frac{H_w^{\,2}}{A\,E}\left(1 + \frac{\beta_1}{2}\right)\beta_1 L_{1s} + H_w\left(1 + \frac{\beta_1}{2}\right)(\omega\, t\, L_{1t} - \delta)$$
$$= \frac{2\,w_1\,l_1}{\pi}\left(1 + \frac{\beta_1}{2}\right)\left(b_1 + \frac{1}{3}\,b_3 + \frac{1}{5}\,b_5 + \ldots\right)$$
$$+ \frac{\pi^2\,H_w}{2\,l_1}(1 + \beta_1)(b_1^{\,2} + 2^2\,b_2^{\,2} + 3^2\,b_3^{\,2} + \ldots) \ldots\ldots\ldots\ldots\ldots (54)$$

and for the main span:

$$\frac{H_w^2}{A\,E}\left(1+\frac{\beta}{2}\right)\beta\,L + H_w\left(1+\frac{\beta}{2}\right)(\omega\,t\,L+2\,\delta) = \frac{2\,w\,l}{\pi}\left(1+\frac{\beta}{2}\right)\left(a_1+\frac{1}{3}\,a_3+\frac{1}{5}\,a_5+..\right) + \frac{\pi^2\,H_w}{2\,l}(1+\beta)(a_1^2+2^2\,a_2^2+3^2\,a_3^2+..) \quad (55)$$

The equation for the deflection of the towers is:

$$\delta = \frac{H-H_1}{E}\int_0^h \frac{y^2}{I_t}\,dy \quad (56)$$

As an example, the data taken from the Final Report of the Board of Engineers to the Delaware River Bridge Joint Commission will be used to determine the values of H, H_1, and δ. It will be assumed that a live load of 12 000 lb. per lin. ft. extends over the entire length of the main span and that there is no load on the side spans. The temperature is assumed to be 55° Fahr. above normal.

Substituting the proper numerical data in Equations (54), (55), and (56): $H = 9\,588\,000$ lb., $H_1 = 9\,391\,000$ lb., and $\delta = 19.90$ in. The value of H which corresponds to the load of 12 000 lb. per lin. ft. is given in the aforementioned report as 9 620 000 lb. and the total movement of the tower as 20.04 in. It is evident, therefore, that the trigonometric-series method can also be adapted for computing the horizontal component of cable stress when the cable is attached at the top of the towers.

A Concentrated Load on the Span.—To simplify the calculation of the stresses in the truss of a suspension bridge it is desirable to set up an equation which gives the effect of a concentrated load on the additional horizontal component of cable stress and construct the influence diagrams.

The equation for determining the additional horizontal component of cable stress produced by a concentrated load on the truss is:

$$\frac{H_w^2\,L}{A\,E}\,\beta\left(1+\frac{\beta}{2}\right) + H_w\left(1+\frac{\beta}{2}\right)\omega\,t\,L_t = \frac{2\,w\,l}{\pi}\left(1+\frac{\beta}{2}\right)\left(a_1+\frac{1}{3}\,a_3+\frac{1}{5}\,a_5+\ldots\right) + \frac{\pi^2\,H_w}{4\,l}(1+\beta)(a_1^2+2^2\,a_2^2+3^2\,a_3^2+..) \quad (57)$$

For this case,

$$a_n = \frac{2\,l^4}{E\,I\,\pi^5}\,\frac{\frac{n\,\pi}{l}\,P\sin\frac{n\,\pi\,c}{l} - 2\,\beta\,w\,(1-\cos n\,\pi)}{n^5+n^3\,\alpha\,(1+\beta)}$$

and the concentrated load, P, is at a distance, c, from the left end of the span.

As an example, Equation (57) will be applied to the calculation of the additional horizontal component of cable stress for the data of the Manhattan Bridge, with the main span regarded as a single span. The concentrated load, P, will be taken as 100 000 lb. and the temperature as normal ($t = 0$). The position of P will be assumed at various points of the span so that its effect

when located at any point in the span may be determined from a diagram. The values of H for various locations of P are given in Fig. 6. With the aid of this diagram, the value of H may be determined approximately for any uniformly distributed load and the influence lines for the bending moment in the truss may be drawn.

As an illustration, it will be assumed that the uniform load extends over the left quarter of the span. It is only necessary to regard the concentrated load, P, as a unit load and then the area bounded by the curve for H, the x-axis, and the ordinates limiting the distribution of the uniform load will equal the component of cable stress for a uniformly distributed load of unit intensity. For an approximation of the area under the curve (Fig. 6) $O\ B\ C$ will be regarded as a triangle and $B\ C\ D\ E$ as a trapezoid. The combined area will equal:

$$K = \frac{0.732 \times 180.9}{2} + \frac{(1.335 + 0.732) \times 180.9}{2} = 253.1$$

For a uniform load of 4 000 lb. per lin. ft., the value of the additional horizontal component of cable stress will be, $H = 253.1 \times 4\,000 = 1\,012\,000$ lb. For similar conditions the value of H as computed by Equation (51) is 1 032 000 lb.

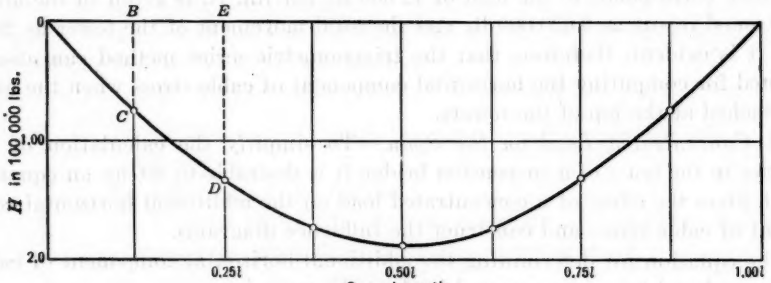

FIG. 6.

The error involved in using this simple approximate method is less than 2 per cent. Thus, it is evident that it may be used to determine a good approximation of the cable stress, H, or the preliminary values of β when the exact method is used for calculating H.

The trigonometric-series method can be used to construct the influence lines and diagrams for the bending moment in the truss. If the bending moment is written as follows:*

$$M = \left(\frac{M'}{y} - H\right) y \qquad \text{.....(58)}$$

in which, y is the ordinate of the cable when the origin is taken at the top of the tower, then the influence line for $\frac{M'}{y}$ may be drawn in the same manner as the influence line is drawn for a simple beam (see Fig. 7). Also, from

* "Modern Framed Structures," Johnson, Bryan, and Turneaure, Ninth Edition, Pt. II, p. 221.

Fig. 6, the influence line for H can be drawn. The area between these two lines represents the influence diagram from which the bending moment due to a uniform load extending over any part of the span may be obtained. The

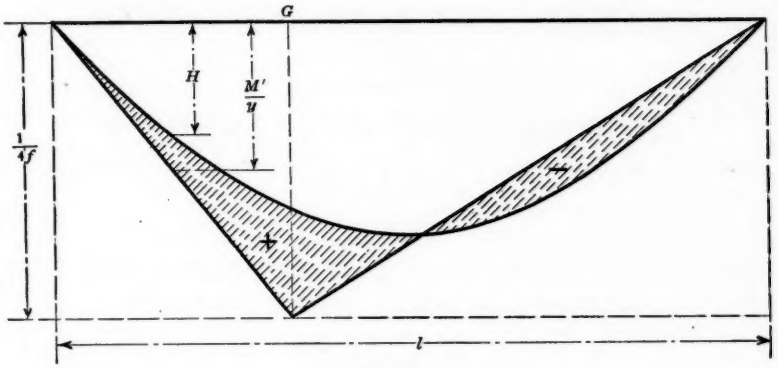

FIG. 7.

shaded area in Fig. 7 represents the influence diagram when the unit load is at the point, G. This method can be used for determining the most unfavorable positions of the live load in calculating the stresses in the truss.

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THE RELATION BETWEEN EARTHQUAKES AND ENGINEERING SUBSTRUCTURES

Discussion*

By Messrs. Walter E. Spear, M. M. O'Shaughnessy, and Bailey Willis.

Walter E. Spear,† M. Am. Soc. C. E. (by letter).‡—The Society is indebted to the author of this paper for a clear statement of the earthquake problem in its relation to engineering substructures. Scientific research may be necessary in order that more concrete information on which the engineer may design earthquake-proof structures may become available, but many practical questions of planning and design may perhaps be answered when the observations on recent earthquakes have been thoroughly studied and interpreted.

A severe earthquake presents the greatest hazard to life and property in large cities, and the main problems there are those of making the buildings safe from collapse, of insuring means of transportation, and of providing sufficient water to prevent a conflagration. Every city has many buildings that would not stand a heavy earthquake shock, but the modern steel frame and reinforced concrete structures appear to be reasonably safe for those who remain inside. The possibility of the cornices falling from these modern buildings and of the brick and stone facings slipping into the streets is not pleasant to contemplate, however, because the first impulse of the panic-stricken occupants will be to rush into the streets. This is the architect's problem, but the engineer should do his part in arousing the public to the need of some revision in the building code that will make streets as well as buildings safer.

* This discussion (of the paper by Henry D. Dewell, M. Am. Soc. C. E., presented at the meeting of the Structural Division, Seattle, Wash., July 15, 1926, and published in August, 1928, *Proceedings*), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Dept. Engr., Board of Water Supply, New York, N. Y.

‡ Received by the Secretary, April 11, 1928.

One of the most serious situations that will result from a heavy earthquake shock in thickly populated sections of a large city is the congestion of the streets by crowds of people and by automobiles and other motor vehicles. The latter proved a great menace during the recent disaster at Tokio, Japan. It is generally conceded that subways and tunnels will suffer little injury from an earthquake. If so, they may provide an avenue of escape from the zone of destruction to the open ground in the parks and on outskirts of the city. This raises the question, whether such structures in the soft silt of rivers and harbors will remain uninjured? Is the integrity of the power houses and the safety of the power ducts assured? Will elevated railroads and viaducts supported on isolated piers of no great depth escape injury? These are all questions for the engineer and now is the time to consider whether transit facilities may be made earthquake-proof at a reasonable cost.

Perhaps the most serious danger in a city shaken by an earthquake is from fire, and one of the engineer's greatest responsibilities is to insure an ample supply of water in such a crisis. In San Francisco, Calif., where fire did so much damage in 1906, the engineers have already given this problem much thought and have now located their trunk water mains on firm ground to insure greater safety. To what extent should this and other measures be taken elsewhere? The author's reference* to the observations of Sir John Milne and the experiments of Sekiya and Omori on the relatively smaller movement in presumably loose ground at depths of 10 to 18 ft. below the surface, suggests the possibility of laying some water mains for fire protection at a sufficient depth in loose soils, perhaps 15 to 20 ft., or more, to insure their safety and of designing the connections to the surface to prevent their rupture. More information on the kind and extent of the movement in unconsolidated formations near the surface is greatly needed.

Professor T. A. Jaggar has pictured† New York in ruins in 1932 following a great earthquake. He correctly represented panic and fire as responsible for the great loss of life, but his recommended remedy was for more seismographs rather than better buildings and a more thoroughly guarded water supply. There is no doubt need of a vast amount of research. Will such research answer the very practical questions that arise and is it necessary to wait before doing something? While New York City is several hundred miles from any well accepted earthquake origin, the possibility of a moderate earthquake may reasonably be anticipated. This city is geologically in the same region as Boston, Mass., where several disturbances have been noted and where an earthquake estimated as Intensity IX‡ occurred in 1755. If a severe earthquake takes place in New York most of the buildings will suffer, some of the tunnels in soft ground may be damaged, and along the waterfront the water mains and sewers will doubtless be broken. The deep rock pressure tunnel under the city, through which is delivered a large part of the city's supply, is undoubtedly safe, however. Another tunnel of the same type is to be constructed. In the new as well as in the old tunnel the only serious

* *Proceedings*, Am. Soc. C. E., August, 1928, Papers and Discussions, p. 1740.

† *Scribner's Magazine*, October, 1924.

‡ By Irving B. Crosby, Geologist, *Transactions*, Boston Soc. of Civ. Engrs., December, 1923.

earthquake problem is in the design of the chambers at the heads of the several shafts through which water from the deep tunnel is delivered and of the connections with the distribution system. Such is the secure foundation and the depth of these chambers that they are reasonably safe from any serious damage, and the city has consequently one dependable source of water to stop a conflagration if the shallow street mains should be ruptured.

M. M. O'SHAUGHNESSY,* M. AM. SOC. C. E. (by letter).†—This paper is very pertinent to problems resulting from action along earthquake faults. The author's explanation of the theory of earthquakes and their causes is very illuminating.

The writer is interested specifically, however, in some of the comments on the earthquake action on dams, referring first to the Upper Crystal Springs Dam, 75 ft. high, which the author states‡ was crossed by a fault line. The fault line crossed over the easterly edge of the dam, practically straddling a connecting pipe line between the two lakes. The pipe was fractured, but the dam was not injured.

The concrete dam at Crystal Springs is about two miles north of the earth dam and is built on an arch up stream, possibly 500 ft. east of the fault line. This dam was built in unit block structures with various rectangular notches to interlock the adjacent blocks. The structure suffered no damage, the concrete being of an excellent character and the dam well built on good foundations. The joints in modern dams would be recessed on angles to remove the shearing stresses due to rectangular notching.

The Sheffield Dam, in Santa Barbara, Calif., was examined by the writer immediately after the earthquake of 1925.§ It was a low earth-fill dam about 30 ft. high. The discharge pipe was placed in a trench of puddled clay in the center of the highest part of the dam. No rock was placed in the down-stream part for drainage. Concrete collars were not used around the outlet pipe, and there was no doubt that, at the period of the earthquake, the body of the dam was saturated and in an unbalanced condition, ready to break. Very fortunately, the water released went down a canyon to the ocean without intercepting any buildings or persons when it failed on the morning of June 29, 1925.

The rock-fill dam at Morena, in San Diego County, Calif., completed by the writer in 1912, is in an earthquake region, west of Imperial Valley, and is constantly subject to earthquake movements, and no damage of any kind has apparently shown in this structure from this condition. Therefore, so far as earthquakes are concerned, the writer would advise that a properly constructed rock-fill dam has a state of equal security with that of the earth-fill dam.

He observed the effects of the earthquake in San Francisco, Calif., in 1906, when 9½ sq. miles of area were destroyed due to the subsequent conflagration and more than $500 000 000 worth of damage was done. The striking evidence

* City Engr., San Francisco, Calif.

† Received by the Secretary, September 12, 1928.

‡ *Proceedings*, Am. Soc. C. E., August, 1928, Papers and Discussions, p. 1742.

§ *Engineering News-Record*, July 30, 1925.

of the reliability of well-constructed buildings is that the earthquake did not damage the U. S. Post Office Building nor the old Customs House Building finished about 1880, although private buildings included in this enormous area collapsed and only seven of them survived the earthquake shock.

An interesting evidence of the survival of a structure on piles is the Ferry Building, at the foot of Market Street, in San Francisco. It was built in 1894 on possibly 3 500 piles, 70 ft. in length, that are held in the mud by skin friction. This building absolutely survived the earthquake without any damage, and there is no evidence of settlement exceeding 2 in. in any part of the building. The zones in San Francisco which consist of filled-in mud are subject to quite a fluctuation. The U. S. Post Office, at Seventh and Mission Streets, was built on piles. The sidewalk on Mission Street was built on the ground surface and settled very nearly 4 ft. after the earthquake. Nearly all the surrounding zone of filled-in land on Mission Creek settled practically to the same depth and, in some places, sidewalks and pavements have moved horizontally at the same time as much as 3 or 4 ft. Fortunately, all the wooden buildings over this ground were destroyed by fire, and the work of restoration of the street survey lines to their original position created quite a problem in the City Engineer's office.

The Hetch Hetchy Aqueduct at Irvington crosses a well-known fault line which was discovered on the ground within the locus of 1 ft., and expansion joints were provided in the 5-ft. pipe crossing at this point.

In the bridge across the bay, at Dumbarton, 3 800 ft. long, over every alternate pier the 60-in. pipe is provided with slip-joints of the same character, and no trouble from earthquake shocks is anticipated.

Four small pipes, 18 and 22 in. in diameter, built on the bottom of the bay in the same locality, by the Spring Valley Water Company, about 1900, survived the earthquake without any damage.

Bailey Willis,* Esq. (by letter).†—The author's contribution to this difficult subject presents an excellent analysis of the actual understanding of earthquake action and points clearly to the fact that there is yet a great deal to be learned. The seismologist distinguishes between absolute intensity and apparent intensity, but his researches deal commonly with the former, whereas it is the latter which is of interest to the structural engineer. The distinction between "absolute" and "apparent" may be described as the difference between the force of the earthquake in firm rock at some depth below the surface and the effect of that force on structures on the surface.

Mr. Dewell's analysis‡ of the longitudinal and transverse waves applies more specifically to the deeper-seated vibrations. The apparent intensity is the effect of the reflected and refracted waves under the peculiar conditions of the surface, and is always likely to be exceedingly complex. Theoretically, seismologists are obliged to conclude that it is impossible to determine, for any given site, what the action of the earthquake force will be, but, practically, they may satisfy the requirements of the structural engineer by assuming a

* Prof. Emeritus of Geology, Leland Stanford, Jr., Univ., Stanford University, Calif.
† Received by the Secretary, September 29, 1928.
‡ *Proceedings*, Am. Soc. C. E., August, 1928, Papers and Discussions, p. 1738.

lateral force as the resultant and assigning reasonable values to it. "Reasonable", in this sense, is a term which is defined by the economic limit of practical construction. It is probably not practicable, except in very rare instances, to build to resist the higher intensities of the earthquake force, but it appears to be within the range of reasonable expenditure to brace and tie structures, including foundations, to resist an acceleration of as much as 5 ft. per sec. per sec., and this is a force which is not likely to be exceeded except in close proximity to the earthquake fault or on an especially bad foundation material.

While agreeing with Mr. Dewell in most of his conclusions, the writer questions the statement* that a structure on deep pile foundations will probably be safe against destruction if the piles are driven to underlying firm material. Whether or not the piles reach firm material would not, in the writer's judgment, materially affect the lateral action of vibrations of wide amplitude at the surface. The tops of the piles are likely to sway back and forth as much as 6 in. or more with the mud in which they are embedded. In so doing they might possibly sink unequally if not driven to a firm foundation, which would be a reason for preferring this stable support where practicable. The writer does not think it possible, however, to argue that the structure would be safe because the risk of unequal subsidence was eliminated. It is the wide amplitude of the motion that is to be feared.

The author very properly emphasizes the difference between the effective action of an earthquake at the surface and at a few feet below it, and argues that deep foundations constitute a condition of relative security.† That security depends on the elimination of the surface movements by leaving a space or a cushion of loose material around the foundation walls. Otherwise, the surface waves of large amplitude, striking against the upper part of the cellar walls and meeting with no resistance from within, are more likely to damage them and so to undermine the building than if the latter stood directly upon the ground. On the other hand, it is obvious that if the structure does stand in a deep pit its vibration as a pendulum will correspond to the whole structure from the base of the foundation to the roof rather than simply from the ground floor up.

The writer has read Mr. Dewell's comment on the security of earth-fill dams with some reservation.‡ The examples which he cites as having safely resisted an unusual shock were in themselves structures which may reasonably be regarded as unusually good of their kind. They were built at a time when earth-fill dams were less popular than they are at present, and by engineers who used every possible precaution. These facts should not be ignored. It has happened that earth dams have been built of materials not suited to the purpose, and it is likely to happen again. It would be unwise to create among engineers or the public an impression that an earth dam is a peculiarly safe structure. It is safe only when built according to the highest engineering standards, and even then it is subject to the limitation that if a break does

* *Proceedings*, Am. Soc. C. E., August, 1928, Papers and Discussions, p. 1741.
† *Loc. cit.*, p. 1743.
‡ *Loc. cit.*, p. 1742.

occur the outrush of water will be far more instantaneous than through a cracked wall of reinforced concrete. The erosive power of a stream of water in soft earth should not be forgotten, and the destructive force of concentrated volume was well shown in the discharge from the Sheffield Reservoir, which swept boulders 6 ft. in diameter down Sycamore Canyon.

The case of the Sheffield Reservoir may serve to call attention to the action of an earthquake on underground water and its effect on the foundations of an earth dam. In any layer of subsoil which is not thoroughly consolidated and which is filled with water, the earthquake vibrations serve to settle the earthy material and, compacting it, drive the water out in the direction of least resistance. Ordinarily, this will be upward, but it may be laterally. Inspection of the foundations of the dam at Sheffield Reservoir after the shock showed a layer of fine adobe mud so saturated with water that it constituted a dense liquid mass on which the dam had floated out. It seems improbable that the dam could long have rested in that unstable condition, and the writer is of the opinion that the earthquake caused the failure of the dam, not by any actual displacement, but by causing the water in the gravelly and sandy subsoil to rise into the adobe which had been placed as a puddle to form an impervious barrier. It is conceivable that similar action might occur in any dam with a core-wall of puddled earth, unless the foundations beneath the latter were thoroughly drained.

With reference to tunnels, the writer would confirm, on the basis of recent observations, Mr. Dewell's statements* regarding their stability when driven in solid rock. At Santa Barbara, Calif., the Mission Tunnel which, with a length of 4 miles, passes entirely through the Santa Ynez Range, and the El Toro Tunnel which, at the time of the earthquake of June 29, 1926, was about 2 000 ft. long, were both in the area of marked activity of that shock. No damage was done to either tunnel, although the effects on the mountains above were such as to dislodge blocks of rock of considerable size. The explanation appears to lie in the fact that the vibrations deep underground, although intensely rapid, are exceedingly small in amplitude; whereas the amplitude at the surface is much greater and is, therefore, destructive, although slower.

The writer agrees heartily with Mr. Dewell that the subject of designing against earthquakes should receive intelligent and careful study, and that engineers should seek by experiment and by mathematical analysis to achieve that understanding which may protect communities against the otherwise inevitable disaster.

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* *Proceedings*, Am. Soc. C. E., August, 1928, Papers and Discussions, p. 1742.

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THE PRACTICAL UTILITY OF HIGHWAY TRANSPORT SURVEYS

Discussion*

By Messrs. R. H. Simpson, W. A. Van Duzer, and C. R. Thomas, Jr.

R. H. Simpson,† M. Am. Soc. C. E.—The author has shown very clearly that a knowledge of how the highways are used is just as essential to the man who directs the activities and policies of a highway system, as a knowledge of the market for a commodity is to a business executive. Engineers have devoted much time and study to the details of pavement construction, and yet it is only recently that they have made an effort to find out the use and abuse to which roads and streets are subjected.

In the design of a bridge, careful consideration is given to the loads to be sustained. Is it not important, therefore, to know the character and density of traffic to be carried in order to decide the type and to construct a pavement properly? A lack of such information in past years has not only led to the selection of types entirely inadequate to handle the volume of traffic carried, but in some cases to the selection and construction of types, the cost of which cannot be justified by traffic conditions. Engineers are beginning to recognize, however, that a knowledge of present, and an intelligent forecast of future, traffic is essential, if they are to design properly and construct roads and pavements economically.

Since a large percentage of the traffic on the main highways of the State originates in the cities, it will be of interest to know something of the movement of traffic in the City of Columbus, Ohio. The Ohio survey shows that approximately one-eighth of the rural roads carries more than one-half of the total road traffic. What percentage of city traffic is carried by the main thoroughfares within that city? What is the relation of traffic to the paved mileage in a city; what is its intensity; its fluctuations, and its character?

* This discussion (of the paper by G. F. Schlesinger, M. Am. Soc. C. E., presented at the meeting of the Highway Division, Columbus, Ohio, October 13, 1927, and published in September, 1928, *Proceedings*), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Chf. Engr., Dept. of Public Service, Columbus, Ohio.

It may not be necessary to know the seasonal variation, but it is desirable to know the direction and maximum intensity of traffic in order to plan intelligently the development of a city. The general direction of traffic will indicate clearly the need of widening present thoroughfares, and will show where additional arteries of traffic may be required.

To obtain a complete and accurate record of the flow of vehicular traffic over the streets of a city presents a problem of some difficulty. It is manifestly impractical to secure information as to ownership, origin, and destination of traffic on a thoroughfare carrying 1 000 vehicles per hour, and such information is hardly necessary in solving problems arising from city traffic. This special problem is rather one of density and calls for information as to direction, total volume, maximum intensity, and something as to the character of traffic.

Traffic counts at best give only an indication of traffic movement within reasonable variation. A count to-day will not agree with one to-morrow or yesterday. The density of traffic at a particular point will vary with the seasons and with weather conditions. It will vary with the day of the week and the hours of the day. Notwithstanding the inexactness of the data, a survey of traffic is very important for the engineer who must plan a system of highways as well as those who must solve the traffic problems in cities.

A few isolated traffic counts were made in Columbus about 1924, but the first systematic survey was undertaken in 1925. The data obtained from this effort, while not very complete, convinced the speaker of the need of continuing the work during the following year. In 1926 a more complete and thorough survey was attempted. The work was under the direction of R. C. Chaney, M. Am. Soc. C. E., Engineer for the City Planning Commission. It was begun on June 14 and continued daily, except Sunday, until September 28. The standard forms prepared for this work enabled the observer to record all traffic movement at a station, so that the movements of any 15-min. interval would be known. Most of the stations were at street intersections, so that the record would show the movement straight through on each street and the right and left turns. The data noted included a count of passenger cars, light and heavy trucks, and horse-drawn vehicles. Data were obtained at 210 stations selected to cover the entire city. The observation period was from 6:00 A. M. to 10:00 P. M. Some Sunday counts were taken at a few stations. At a number of selected stations a complete 24-hour count was taken, and, at a few, the movement was observed for seven consecutive days. Many of the stations were handled by a single observer, but on heavily traveled thoroughfares, two observers worked together.

While the survey covered a 16-hour day, a 13-hour day was adopted for the purpose of this study, from 6:00 A. M. to 7:00 P. M., as a standard interval best suited to give a dependable average traffic. This period covers the business day, both commercial and commuting, and the traffic during this interval is fairly uniform throughout the year. The traffic for this interval is about 70% of the 24-hour traffic.

There are in Columbus about 540 miles of dedicated streets. Of this total, 400 miles are improved. The remainder of the mileage is not improved, so

that practically all the traffic movement of the city is carried by the 400 miles of improved streets. The roadways vary in width from a minimum of 18 ft. to a maximum of 80 ft., the average being about 30 ft.

Of this paved mileage, 48.12 miles, or 12.03%, may be classed as main thoroughfares, arteries that lead from the center of the business district in all directions to the suburban sections; 38.25 miles, or 9.56%, may be classed as secondary thoroughfares; and 313.62 miles, or 78.41%, as minor streets. The average daily movement (13-hour interval) on these roadways is as follows:

Main thoroughfares.....	7 000 vehicles, or	336 875 car-miles
Secondary thoroughfares..	3 434 vehicles, or	131 370 car-miles
Minor streets.....	410 vehicles, or	125 450 car-miles
Total daily movement.....		593 695 car-miles

This equals a movement of abount 9½ miles per day for each registered car in the city.

It is interesting to note that the main and secondary thoroughfares, representing 21.59% of the paved mileage, carry 81% of the traffic movement. It will be noted, also, that the main thoroughfares, representing 12.03% of the paved mileage, carry 56.7% of the traffic movement. This fact is rather striking in that it agrees closely with figures presented by Mr. Schlesinger on the relation of traffic on the State routes as compared with the total rural traffic movement.* In other words, the traffic movement on the main thoroughfares of the city bears about the same relation to the total traffic in the city streets as the traffic on the State routes bears to the total rural traffic.

The character of the traffic on city streets is of some importance. The Columbus survey shows that an average of 16% of the vehicular movement is motor trucks, and that approximately 25% of these trucks were classified as heavy, so that about 4% of the traffic consists of heavy trucking units. The movement of horse-drawn vehicles is negligible because less than 1% of the traffic is of this class.

Figs. 9 and 10 show the variation of traffic in the city compared with that of the State highways, the data on the latter being from the Ohio survey as presented by Mr. Schlesinger.† Fig. 9 shows the hourly variation expressed as the percentage of traffic during the average hour. It will be noted that the intensity of highway traffic increases rather uniformly from a minimum at 4:00 A. M. to a maximum at 4:00 P. M. The traffic intensity in the city, however, while rising rapidly in the morning, is fairly uniform from 8:00 A. M. to 4:00 P. M. The maximum intensity is about 6:00 P. M., followed by a slump with another peak in the early evening.

Fig. 10 shows the daily variation of traffic expressed as percentage of traffic during the average day. The traffic intensity on the highways reaches a maximum on Sunday, while in the city it is a minimum on that day. On the highways, the Saturday and Sunday traffic is more than the average and, in the city, the traffic intensity exceeds the average on Monday and Saturday.

* *Proceedings*, Am. Soc. C. E., September, 1928, Papers and Discussions, p. 2075.
† *Loc. cit.*, p. 2079, Fig. 6.

Studies in Columbus have not been carried to a point where a complete thoroughfare plan can be outlined for the needs of the city, but in a number of locations it has furnished evidence to show the need of wider roadways and new thoroughfares. The traffic survey has been an aid in determining the

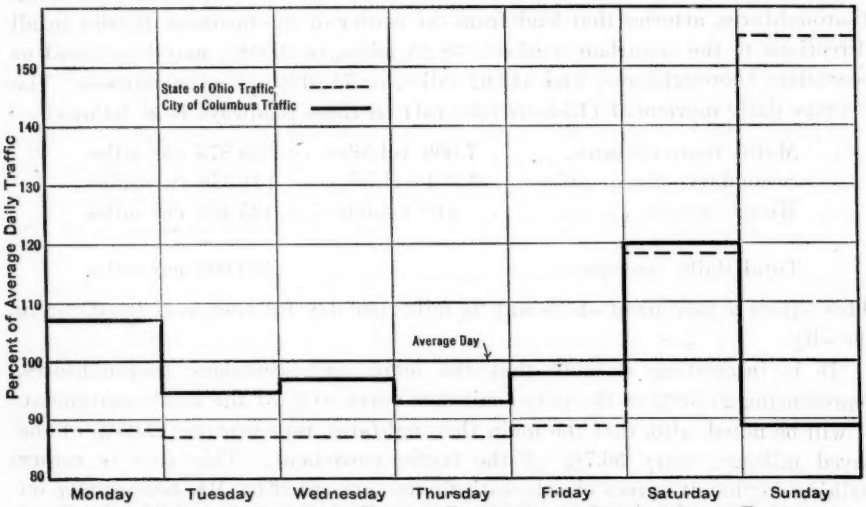

FIG. 9.—HOURLY VARIATION OF TRAFFIC EXPRESSED AS PERCENTAGE OF TRAFFIC DURING THE AVERAGE HOUR.

proper location and the proper width of arteries extending into newly developed territory and in planning the development of suburban areas. It has also furnished evidence to aid in the selection of locations for the installation of automatic traffic signals.

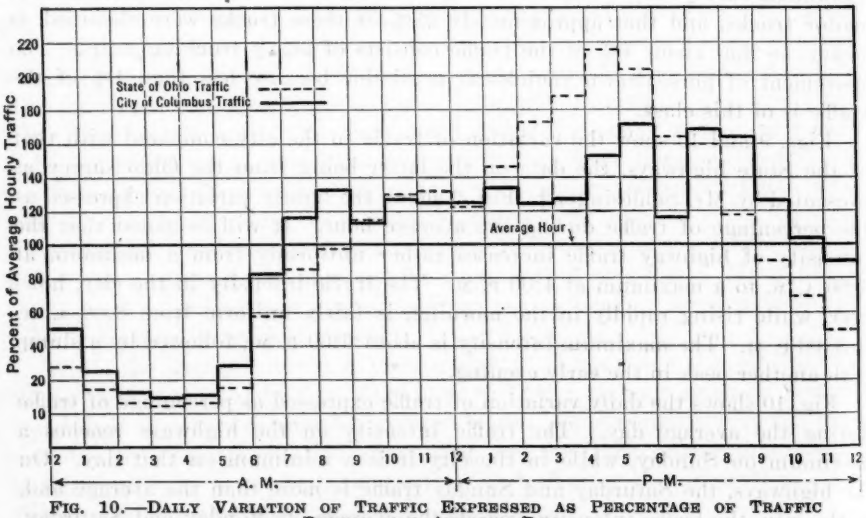

FIG. 10.—DAILY VARIATION OF TRAFFIC EXPRESSED AS PERCENTAGE OF TRAFFIC DURING THE AVERAGE DAY.

The traffic on the streets should also be studied in an effort to determine its effect on pavements. What is the relation of traffic to the wear and repair

of pavements? A few years ago this question was of little moment, but the use of self-propelled vehicles has reached such proportions as to show its effect on pavement surfaces. To-day many hard-surface pavements which carry a large volume of traffic are showing abrasive wear, especially where the traffic is concentrated in narrow lanes and has no opportunity to spread over a wide area. A test of a concrete pavement by the U. S. Bureau of Public Roads, at Arlington, Va., showed an abrasion under concentrated traffic of nearly 0.01 in. by the passage of a vehicle 55 000 times over the surface. At the same ratio 1 000 000 vehicles would have resulted in a wear of 0.17 in. Some observations by the speaker on a pavement in Columbus, carrying 5 000 000 vehicles yearly, shows that rubber-tired traffic will abrade hard surfaces, and there is evidence to show that the abrasion is approximately proportional to the volume of traffic. When it is realized that many pavements carry a traffic in excess of 2 000 000 vehicles yearly, it is clear why many of them are showing signs of distress, and why such vast sums are required for maintenance. Is it not important, therefore, to have a knowledge of the traffic conditions in order not only to plan the future development of rural and urban communities intelgently, but to design and construct pavements properly? The time is past when pavements should be constructed without reference to the use to which they are to be placed. The engineer should know within reasonable limits the density and character of the traffic to be carried. The only way to secure this information is by a traffic and transport survey.

W. A. VAN DUZER,* M. AM. SOC. C. E.—As Mr. Schlesinger states,† the principal application of evidence produced from highway transport surveys is as bases of plans for future highway improvement. Furthermore, the value of a transport survey is cumulative. A great deal of the evidence may be of little or no utility at the time it is gathered, but may become valuable in the future, in combination with later data indicating trends important of consideration in connection with making or modifying plans for improvement, or in connection with traffic control.

The principal information that is secured from the highway transport survey is as to distribution and annual daily average of traffic flow, wheel loads, and peak loads; and the greatest value of this information is in its use with trend curves. Past records and present information with future trends furnish a conception of future conditions.

The author gives a very clear description of the Ohio Transport Survey and its uses. Summarizing, and at the same time generalizing, the speaker would say that a highway transport survey furnishes information pertinent to the economic development and profitable and safe utilization of the highways.

Priority of Improvement.—Information as to distribution of traffic flow makes it possible to classify the highways of a system for priority of improvement. Mr. Schlesinger indicates this and he also states‡ that motor highway traffic is of recent and incomplete development.

* Deputy Eng. Executive, State Dept. of Highways, Harrisburg, Pa.

† *Proceedings*, Am. Soc. C. E., September, 1928, Papers and Discussions, p. 2073.

‡ *Loc. cit.*, p. 2083.

In twenty years, highway traffic has changed from horse-drawn to motor-driven and in volume has probably increased fivefold. Since 1908 the necessity for greater strength and durability has increased the cost per mile of pavement construction approximately five times, while the demand for more mileage has increased in even greater proportion.

At present, the pressing task is to provide a durable, hard surface on a vast mileage of trunk highway systems, and the highway transport survey may be considered as furnishing data for use in solving the problem of priority of improvement.

In general, the total volume of traffic, as, for instance, when expressed in total vehicle-miles, is a measure of the value of road service. In order to determine the merit or efficiency of any road system, it is necessary that the value of the road to the road user—which may be considered as the saving in operating over improved, rather than unimproved, roads—be capable of balancing against the cost of furnishing improved roads.

As an illustration, it is estimated that total travel on the Pennsylvania State Highway System in the next four years will average about 10 000 000 000 vehicle-miles per year; that there is a 25% saving in operating over improved road, equivalent to 2½ cents per mile for passenger-car travel and 9 cents per mile for motor trucks and buses. Assuming 10% motor-truck and bus traffic, the annual saving is about $225 000 000 for passenger cars and $90 000 000 for motor trucks and motor buses, or a total of $315 000 000 per year for all traffic. It is very important that the capital charges plus upkeep of the State highway investment show a profit to the public. Admittedly, estimated unit savings are open to question; but the figures appear to be reasonable, and until the road costs approach such total as would be equivalent to savings computed by using such lower savings figures as might be advanced, the question as to accuracy of the estimate is not critical. The more definite determination of savings figures, however, may prove important in the future and it is through traffic surveys and studies that the improvements in accuracy can be obtained.

Location.—The improvement of any route, or any section of a route, raises questions which can only be disposed of satisfactorily by comparison of costs. If, for example, there are two alternative locations, one of which will cost $30 000 per mile for grading and the other $20 000, and if the larger expenditures result in a shortening of distance or a reduction of maximum grade, the number of vehicles using the road will determine which of the two is the preferable and economic location.

Selection of Type.—The information as to distribution and annual daily average (Table 1*) is valuable in the solution of the problems of highway economics in determining the type of improvement.

It is an engineering precept that there should be an estimate of load to be carried, by any structure, throughout its economic life. In the past years traffic has been developing and changing at such rapid rate—while adequate standards of construction were being developed—that forecasting has been virtually impossible; but now that the rate of increase has moderated, a curve

* *Proceedings*, Am. Soc. C. E., September, 1928, Papers and Discussions, p. 2077.

of future traffic can be drawn with some logical basis. There are now modern types of pavement which have been carrying traffic a sufficient length of time to warrant estimating the length of their economic life. The relation between volume and weight of traffic, and costs of construction and maintenance of pavement, has become sufficiently stabilized so that it can be observed and studied to verify or correct the assumptions on which the present huge expenditures on highways are based and on which in the future greater expenditures are to be planned.

Design of Pavement Section.—Information as to weight of heavy wheel loads and their frequency makes it possible to provide a pavement section of sufficient strength to withstand—without destructive cracking—the loads to which it will be subjected. Conversely, information as to what wheel loads are being carried without serious damage, and what wheel loads are excessive for various types of pavement, will furnish evidence to verify or correct present ideas concerning requirements of cross-section and materials.

Information as to volume and nature of peak loads to be carried and capacity of multiple-lane or parallel roads, under traffic characteristic of locality, is also essential for planning, intelligently, the width of road surfaces. There may not be general agreement as to what should be considered the maximum carrying capacity of two, three, or four-lane roads, under different conditions. It is within the last few years, and only in a comparatively limited mileage, that carrying capacity of two-lane roads has been exceeded, and even now the composition of traffic is still changing. There is, as yet, a wide variation in proportions of motor-truck and bus traffic to be considered in the present as well as estimated in the future. These considerations, however, emphasize rather than detract from the importance of traffic survey data in connection with the planning of improvements.

Time Factor.—The principal features of the highway transport survey have been considered to be those which most directly affect the road itself. This has been the point of view necessarily taken during the early stages of development of the road system. With the road system approaching completion, the point of view changes to embrace operation as well as construction. In the future, highway administration may be expected to concern itself more and more with operation and traffic control.

Time is an ever-increasingly important factor. Pavements might withstand the full weight of traffic and carry the full volume of it and yet be unsatisfactory if travel entailed loss of time. It is necessary to provide highway facilities for fast as well as slow travel, as in the case of railroads. In the near future, widening of roads with special lanes for slow travel, or segregation of slow travel to parallel roads, for the purpose of reducing congestion, is likely to occasion large expenditures and, in such cases, adequate information will be required.

With the understanding that road design is to permit occasional over-loads, in the same way that storm sewers are designed to be occasionally overtaxed, the peak load of traffic, expressed in hourly rate, rather than annual daily average, should be the measure of highway capacity. The planning of multiple

lanes and parallel roads will be influenced accordingly. Width of right of way as well as width of pavement is involved.

In many cases, especially on trunk roads entering cities where it may not be possible to provide either extra width or parallel roads, unsatisfactory conditions may be remedied by eliminating or reducing to a minimum those features which retard the flow of traffic and constrain the volume-carrying capacity of the road. Such features, concerning which a traffic survey may furnish very valuable information, are railroad crossings, cross-road or side-road intersections, sharp curves, and steep grades.

Safety.—The purpose of the highways is their safe and profitable use. Safety requires, essentially, jurisdiction over drivers and minimum specifications, particularly as to brakes and lights. The growing accident loss is to be checked and the proper use of the highways is to be encouraged. This feature of highway traffic study must receive a great deal more consideration in the future and traffic-flow data must be combined with accident-occurrence data to furnish an accurate conception of the problem which is pre-requisite to remedy.

TABLE 11.—1926 STATE HIGHWAY ACCIDENT HAZARD BY DAY OF WEEK.

Day.	Percentage of accidents.	Percentage of traffic.	Factor.	Relative hazard.
Sunday	18	24.5	73	100
Monday	15	12.1	124	170
Tuesday	13	11.1	117	160
Wednesday	11	11.8	93	127
Thursday	12	12.1	99	136
Friday	12	12.8	94	129
Saturday	19	15.6	122	167
Total	100	100.0	....	....

Table 11 furnishes an example. It shows that in 1926, of accidents reported as occurring on the State highways of Pennsylvania, the percentage charged to Sunday was greater than that for any other day of the week, but when daily average of traffic is taken into account, it is found that Sunday is the day of lowest relative hazard. In connection with the analysis of accident data, it is obvious that the number of accidents is significant and important, but it is also obvious that comparison is valuable; and in this case a comprehensive comparison must include the indication of accident rate in terms of total volume of traffic. Public welfare requires traffic control, and traffic control necessitates traffic information.

C. R. THOMAS, JR.,* M. AM. SOC. C. E. (by letter).†—The analysis made by Mr. Schlesinger shows rather clearly the importance of a study of population figures in planning roads. "The volume of highway traffic in an area is largely a function of the population of the area," as stated‡ and proved by the author

* Editor, *Highway Engineer and Contractor*, Chicago, Ill.

† Received by the Secretary, October 22, 1928.

‡ *Proceedings*, Am. Soc. C. E., September, 1928, Papers and Discussions, p. 2081.

for Ohio, is also a fundamental proposition laid down by the late A. M. Wellington, M. Am. Soc. C. E., as applied to railroads. The development of modern highway traffic is producing conditions that are more and more like those that apply to railroads and telephone companies. Similar methods of analysis, which have reached a high degree of refinement in railroad and telephone traffic studies, may be applied with some degree of success to an analysis of highway conditions.

For purposes of predicting future traffic on a route, the great value of a traffic survey seems to be that it establishes the fact that highway traffic in general varies with population. In other respects, a traffic survey is like "locking the stable door after the horse is gone." The traffic is already there. Just how much traffic may be expected and what set of conditions will produce a given traffic is the information that the projector of a highway wants.

In cases where the traffic did not seem to vary so exactly with the population on the State roads, the author states* that other roads carried the traffic. Might it not also be assumed from the same data that the economic location of the State road was poorly made—the road was not in the right place?

Another interesting conclusion is that only 14% of the traffic exceeded a 50-mile limit of trip†—through traffic is relatively small. An analysis of traffic from the standpoint of the area served would seem to be possible, and such an analysis should give interesting and useful information, especially in predicting traffic.

The determination of the potential traffic in the area would give maximum figures useful in designing. The variable of "attraction of traffic" is eliminated by assuming that the road properly improved will get all the traffic, much of which is now going by other routes. This, of course, applies only to the local 50-mile haul traffic, which in Ohio is 86% of the total.

The subject is one that might be discussed and elaborated at length with interesting results. Suffice it to say that the old railroad principle of location holds true, namely, that there is one best route between two points or a group of points; that this route should be found and improvement made in proportion to the traffic to be anticipated when the traffic area is developed to its full present possibilities; and if funds are available it may be wise to anticipate future traffic possibilities of the area.

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* *Proceedings*, Am. Soc. C. E., September, 1928, Papers and Discussions, p. 2082.
† *Loc. cit.*, p. 2081.

MEMOIRS OF DECEASED MEMBERS

HENRY SEWALL ADAMS, M. Am. Soc. C. E.*

DIED AUGUST 21, 1927.

Henry Sewall Adams, the son of Charles Sylvester and Christiana Wyman (Jennison) Adams, was born in Cambridge, Mass., on March 16, 1864. At an early age he lost his parents, as well as his only brother and sister, and his boyhood was spent with his Grandfather Adams, in Cambridge, and at the farm of his Grandfather Jennison, in Burlington, Mass.

At the age of seventeen, Mr. Adams began his engineering career with a survey party on the sewerage system of Woburn, Mass., work which occupied four summer vacations during his course at the Woburn High School and following his college Freshman year. In 1883 he entered the Massachusetts Institute of Technology where he studied civil engineering with the Class of 1887, leaving, however, before graduation, to take a position in the office of the City Engineer of Cambridge.

Municipal engineering work in Cambridge and work as Assistant County Engineer of Middlesex County occupied Mr. Adams until 1893, when he opened his own office in Boston, Mass., for the private practice of engineering, a practice which was continued uninterruptedly until his death.

In the early years of his private practice, Mr. Adams' professional work included water-front developments at Boston, reporting on mines in Montana, Idaho, California, and Mexico, and on other properties in different parts of the country. In 1895 was begun the construction of Boston's Subway System, the pioneer undertaking of its kind in the United States. This extensive work of underground construction presented new and unusual problems relative to the underpinning and safety of buildings. In the several years during which subways and tunnels were being built in down-town Boston, Mr. Adams, more often than any other engineer, was called upon by private clients to advise on these foundation problems and to look after the safety of more than one hundred important buildings.

Gradually, work on difficult foundations, and more particularly that in connection with the building of water-front structures, came to absorb Mr. Adams' attention. In this special field he made a reputation which was not confined to Boston. Not only did he come to be looked upon as the leading engineer in private practice on the development of the Boston water-front—and no engineer has been more closely identified with private developments at that port—but his services were in demand elsewhere. He was one of two engineers commissioned by the City of Newark, N. J., in 1909, to study and report upon the layout of the port development of the Newark Meadows; he designed wharves and docks for Ponce, Porto Rico; he designed and supervised the building of the Sandy Bay improvements at Rockport, Mass.; and he was Engineer on harbor and water-front improvements at other ports.

* Memoir prepared by Frederic H. Fay, M. Am. Soc. C. E.

For many years, until his death, Mr. Adams was Consulting Engineer to the Atlantic Sugar Refineries, Limited, of Montreal, Que., Canada., on its water-front plant at St. John, N. B., Canada, where his advice was sought not only on difficult water-front problems, but also on the general development and upkeep of the plant. Likewise, for many years he was Consulting Engineer to the Pocahontas Fuel Company, Incorporated, in connection with its coal-handling plants at Portland, Me., and at New Bedford, Mass. At both Portland and St. John, he successfully met some unusually difficult problems of water-front construction in connection with structures, previously built by others, which had failed. Many fuel companies engaged his services in connection with the building and repair of coal-handling plants. Included among his clients were railroad and steamship companies and many corporations, as well as most of the private wharf owners along the Boston water-front.

Mr. Adams showed peculiar ingenuity and resourcefulness in solving problems of unusual difficulty and complexity. Painstaking and thorough in his work, he was also a man of broad outlook and sound judgment. By his clients, many of whom he served continuously over a period of years, his advice was sought, not only on structural problems, but also on the conduct of business.

For more than thirty years, and until his death, Mr. Adams lived in Arlington, a suburb of Boston. He retained also the farm of his Grandfather Jennison in Burlington, where part of his boyhood had been spent and in which he always took a special interest. He served the Town of Arlington in many ways. During the early years of his private practice, and until the appointment of a full-time Town Engineer, he acted as Engineer for the town and took an important part in the laying out and development of this growing community. He was elected a member of the Board of Public Works of Arlington in 1912, a position which he filled for several years, part of the time being Chairman of the Board. He was elected a member of the first Planning Board of the town in 1914.

Being deeply interested in historical and genealogical matters, he was long an active member of the Arlington Historical Society as well as of the Bostonian Society.

Mr. Adams was admitted to membership in the Boston Society of Civil Engineers on October 19, 1892, and served as a Director of that Society in 1925 and 1926. He was a life member of the International Association of Navigation Congresses; a member of the American Society for Testing Materials, and of the Association of Professional Engineers of the Province of New Brunswick, Canada. He was a member of the Engineers Club of Boston and of the Boston Chamber of Commerce, in which latter organization he took an active part in the work of the Maritime Association.

In October, 1892, Mr. Adams was married to Bessie Lockwood Tucker, of Cambridge. He is survived by his widow and four sons, Charles Jennison, Laurence Wilder, Ralph, and Henry Sewall, Jr. There are also two grandchildren, Jane and Charles Jennison, Jr.

By ability and achievement, he worthily earned a position of standing in the Engineering Profession. Ever modest, genial, and true to his own high

standards, he endeared himself to a wide circle of friends and associates. Especially was he held in high regard by the clients whom he served. One of them writes:

"Mr. Adams had the happy faculty of always impressing his client with explicit confidence in his judgment, and I never knew a more careful and painstaking man than he when he had a difficult problem confronting him, and he had one of the most lovable natures that I ever knew in a man of his ability. Our Company has suffered a great loss in the death of Mr. Adams."

Another client says of him,

"The recital of Henry S. Adams' services to this company would be a long and unbroken record of valuable contributions. He possessed an engineering ability that in itself was sufficient to distinguish him, but over and above this was a pride and joy in his work and a simple devotion to an ideal which, combined with his professional ability, gave him that place and position which he occupied so well. Possessed of a delightful modesty and never superior to gaining information from whatever source it might be offered, he none the less inspired full reliance by his own quiet confidence.

"It is, however, impossible to consider Henry S. Adams except it include his own charming and lovable character. The start of our business relationship marked also the beginnings of a personal attachment which grew and deepened until it became one of life's delightful realities. It is a great privilege to have had him as a friend and to continue him in our affectionate remembrance."

An able engineer and useful citizen, Henry Adams was a lover of Nature, a devoted husband and father, and a loyal and understanding friend.

Mr. Adams was elected a Member of the American Society of Civil Engineers on June 6, 1906.

GEORGE HERBERT BOYNTON, M. Am. Soc. C. E.*

DIED APRIL 20, 1928.

George Herbert Boynton was born at Meredith Village, N. H., on September 3, 1852, the son of Emory Warren Boynton and Mary (Cram) Boynton. His early boyhood was spent in the neighborhood of Watertown, Mass. He began his education at the age of three, in Lawrence, Mass., while accompanying his brother to the little "old red brick school house", which was still standing a few years ago. He, thus early in life, showed himself very persistent in any thing he undertook, consequently, his father found it necessary, at times, to carry him to school through stormy weather.

When Mr. Boynton was six or seven years old, he began his business life by delivering papers. About this time his mother died. After a few years his father was married to Eliza Hilton, who was an exceptionally fine woman, and no boy ever could have been a more devoted son than Mr. Boynton was to her until she died in her seventies.

In 1866 the family moved to Rock Island, Ill., where he attended the public schools. Soon thereafter he went to work on the Government Island where he served as Time-Keeper for a short period. In order to be early, so that he

* Memoir prepared by H. W. Zeug, Secretary, Northern Gravel Co., Muscatine, Iowa.

might set an example for the many men employed there by "Uncle Sam", he was obliged to get up before daylight, as he had to cross the Mississippi River and walk several miles to the head of the Island. At one time, owing to great damage by storms to the wagon bridge, he found it necessary to walk the railroad bridge. When one stops to consider the darkness, the snow, and the ice, one may realize, somewhat, the energy and ambition of a "young man" not yet seventeen. He was never late and never complained. His method of "carrying on" then, was typical of his whole after life.

Mr. Boynton next engaged in office work at the Rock Island Arsenal, and was shortly appointed Assistant to the Chief Draftsman, Mr. Otto Gronen. While thus occupied, Lieutenant Shaler became so much interested in him, that he gave him a liberal course in mathematics. It was largely due to the interest shown by his two superiors, that Mr. Boynton decided to make an effort to continue his education along engineering lines. With the encouragement and help from his family and a good friend or two, whom he later repaid, he succeeded in going to Germany in 1872, where he entered the Polytechnic School in Chemnitz, Saxony. He at once took up the strenuous task of beginning the study of German and his engineering course in that language, at the same time. He came out with flying colors in both studies and was graduated in 1875. Later in life he found much pleasure in German literature.

When he first entered the Polytechnic School he met a Norwegian of about his own age. They were attracted to each other in the unfamiliar land in which they met. At any rate, a friendship was formed which was still loyal and touching at the time of Mr. Boynton's death. "George" spent his vacations in Norway at the home of "Jens" Skougaard, and "Jens" afterward visited his friend's home in the United States many times.

After three years of study, Mr. Boynton returned to Rock Island, ready and eager to go to work. For a time he carried on a private practice. In 1877, he was made City Engineer. This work, apparently governed largely by politics, was not entirely to his liking, and at the expiration of his term of office, in 1878, he went to the Chicago, Rock Island, and Pacific Railway Company, expecting temporary employment only, but evidently he was successful, as more and more important duties were given him, and he remained with that Company for twenty-nine years. During the first summer, he was appointed Assistant Engineer on a survey of the Mississippi River between Keokuk, Iowa, and Grafton, Ill. In the fall of 1879, he was appointed Assistant Engineer with headquarters in Davenport, Iowa. He was there for twenty years, being then transferred to the Chicago Office, where he remained until his resignation in 1907.

In 1908 he returned to Davenport and entered the general contracting business, being engaged in the construction of bridges and railroads, until 1914, when he organized the Northern Gravel Company, of Muscatine, Iowa, where he went to live a few years later. He was elected President of the Company, and held that office until he died on April 20, 1928.

Before the World War was declared, Mr. Boynton was made a member of the Naval Construction Board of the United States, organized for industrial preparedness, Mr. Thomas A. Edison being Chairman. Mr. Boynton gave his

services to his country as one of the State Directors, as long as the Board continued to function.

In 1884, he had a prolonged and serious attack of typhoid fever. The first thing to make an impression on him when he came back to his normal conscious life was a notification that he had been elected to membership in the Society. It was dated September 3, 1884, which happened to be his thirty-second birthday. On November 30, 1918, thirty-four years later, he received another official notice from the Society stating that, "A Corporate member who has paid dues twenty-five years, and is seventy years old, is exempt from further payment of dues", and it further stated that he had been made a "Life Member of the Society". While for various good reasons he never took an active part in the Society's work, he was much interested in its activities and kept in touch with them, at the same time enjoying the friendship and acquaintance of many of his fellow members.

Mr. Boynton possessed a lovable personality and although he was rather quiet and reserved, his kindly interest in people, especially in younger men, seemed to invite and inspire confidence. With his high ideals of life and integrity, his own daily life seemed to be a helpful influence to many with whom he came in contact.

During the years he lived in Muscatine, he made warm friends, both in his social and business life. He was a dependable and valuable member of the Board of Directors of the Hershey State Bank and was often called on for counsel and advice in the affairs of the city. He was a member of the Geneva Golf and Country Club and, when living in Davenport, was at one time President of the Outing Club. Mr. Boynton was a great home lover, and was fortunate in having a comfortable old-fashioned house on the bluff overlooking the Mississippi River. He was never so happy as when at home with his wife and books by his side, having been an inveterate reader from childhood. While fond of music, having inherited a good voice and ear from his mother, walking and reading were his main recreations. Consequently, it was an unusually great sorrow when in September, 1927, an acute attack of glaucoma demanded an immediate operation, which allowed no more reading or writing. For years one of his favorite maxims had been, "there is no use kicking against the pricks", and there was little complaining; on the contrary, a feeling of thankfulness that he had been spared pain and that being in apparently excellent health, he could do everything as usual, except read and write.

It was a great shock to every one when, with no warning whatever, he was suddenly stricken with angina pectoris on January 13, 1928. He suffered great pain for a few days, which was followed by exhaustion. Continued rest and relaxation brought back his strength in no small degree, and for many weeks out of the fourteen in which he did not leave his room, he kept in constant touch with his business and the affairs of the Nation.

It may be of interest and appropriate to quote here an article that appeared in the *Muscatine Journal,* as it seemed to meet with the approval of many. It was written by a beloved and admired friend, a rather widely known historian and writer. The heading was:

"A Certain Man

"Men there are who, when taken from the world, leave it poor indeed. Such a man was Mr. George H. Boynton, of Muscatine. Mr. Boynton had a mind of technical bent. Technical things attracted him. A Civil Engineer, he so followed his calling as to be honored with membership in the American Society of Civil Engineers, later being made an Honorary or Life Member.

"But it is not of Mr. Boynton's practical aptitudes that the writer would speak. He had qualities far rarer. These caused him to be known as 'of the old school', a man of courtesy, of chivalry, a gentleman. Old Thomas Decker hesitated not to describe 'The best of men that e'er wore earth about him' as simply 'the first true gentleman'. Distinguished for courtesy, for kindliness, Mr. Boynton did not lack firmness; he was steadfast, he stood four-square to any winds that blew.

"A man's education, his training may or may not single him out. Mr. Boynton's training singled him out notably. In the main, he gained it in Germany. It was thorough—that was German. It was scrupulous—that was New England. Mr. Boynton's scrupulous thoroughness marked him from first to last. The particular thing that was just—this to him—was the vital thing.

"Kindliness evidenced in courtesy; courage evidenced in steadfastness; honor evidenced in scrupulous regard for what was just—such was Mr. Boynton's life."

On December 31, 1889, Mr. Boynton was married, in Davenport, to Frances E. Cutter, of Rock Island, who survives him.

The funeral service at his home in Muscatine was simple and modest—as typical of the man, and as he would have wished it to be. The concluding sentence of this service was most appropriate and covered his whole life. It was: "And so: We leave our brother—our friend—the husband who was still the lover".

Mr. Boynton was elected a Member of the American Society of Civil Engineers on September 3, 1884.

WILLIAM SANBORN DAWLEY, M. Am. Soc. C. E.*

Died May 18, 1927.

William Sanborn Dawley, son of John T. and Lemoille (Sanborn) Dawley, was born November 27, 1856, at Stockton, Wis.

He was graduated in 1879 from the University of Minnesota with the degree of Bachelor of Civil Engineering and immediately joined the ranks of those pioneers who were so busily engaged at that time in locating and building railroads.

Mr. Dawley's earlier apprenticeship, like that of most engineers of his time, consisted of a rapid succession of moves from one scene of activity to another. During the ten years immediately following his graduation, he was successively Rodman, Levelman, Transitman, Locating Engineer, Resident Engineer, and Division Engineer on various railroad location and construction projects for the Minneapolis and St. Louis Railroad, the Great Northern Railway, the Minneapolis, St. Paul and Sault Ste. Marie Railway, the Chicago and Indiana

* Memoir prepared by Baxter L. Brown, M. Am. Soc. C. E., and Milton M. Kinsey, Assoc. M. Am. Soc. C. E.

Coal Railway, and the St. Paul and Kansas City Railroad Companies. His activities during this period covered the greater part of Minnesota, Wisconsin, Iowa, North Dakota, South Dakota, and Indiana, but there were in addition three outstanding accomplishments.

The location of the Minneapolis and St. Louis Railroad, in 1884, which extended as far west as Watertown, S. Dak., was Mr. Dawley's first work in charge of location. This line ran through the Dakota Hills and necessitated some heavy grading and bridge work. He also located and platted fourteen town sites along this line.

In 1885 and 1886, Mr. Dawley first located and then constructed 65 miles of the Chicago and Indiana Coal Railway, which later became the Indiana Division of the Chicago and Eastern Illinois Railway. The following year he was in charge of construction of 30 miles of line southwesterly from Des Moines, Iowa; this line later was incorporated as one of the component parts of the Chicago-Great Western Railroad.

In 1888, Mr. Dawley became Special Assistant Engineer to the Vice-President of the Chicago and Eastern Illinois Railway Company, with which road he remained until 1906, having been made Principal Assistant Engineer in 1890 and Chief Engineer and Engineer of Maintenance of Way in 1894. In many respects, this was the most active period of his life and the one of greatest responsibilities. Railroad mileage was being extended at a rapid pace, and Mr. Dawley had by this time a reputation as a railroad builder which made his counsel much sought. In addition to being in full charge of all engineering work, both construction and maintenance, for the Chicago and Eastern Illinois Railway Company, he located and, subsequently, built the extension from Tuscola to Shelbyville, Ill. Later, he extended the line in Illinois to Thebes on the Mississippi River and to Joppa on the Ohio River. During this 18-year period, he located and constructed more than 500 miles of railroad. In addition, Mr. Dawley re-designed and rebuilt the yard at Danville, Ill., and the Terminal Yard at Dolton, Ill.

In 1906, Mr. Dawley left the Chicago and Eastern Illinois Railway Company to become Chief Engineer of the Missouri and North Arkansas Railway Company. In the following three years he located 210 miles of new line in Missouri and Arkansas, about one-half of which was in the Ozark Mountains, and required heavy grading and a large number of steel bridges, including a 300-ft. draw-span over the White River. He purchased the right of way for this line and completed its construction, having expended in three years more than $5 000 000.

In 1909, at the earnest solicitation of Onward Bates, Past-President and Hon. M. Am. Soc. C. E., Mr. Dawley signed a contract as Chief Engineer of the newly formed Yunnan, Szechoan and Teng Yueh Railway Company of China. Mr. Bates had just returned from a trip to China and had been asked to assist in the selection of an engineer for the railway. On his arrival at Yunnan Fu in Southwest China, Mr. Dawley found it necessary to train twenty young Chinese in the art of surveying before he was able to commence the work of location. His success at this unusual engineering task is evidenced by the fact that in the next four years he had completed the exploration and

reconnaissance surveys for more than 1 400 miles of railway and the preliminary and final location surveys and estimates for 600 miles of additional track. All this work was in the extremely mountainous district of Southwestern China.

The unsettled condition of the country and the Revolution which resulted in the formation of the Chinese Republic produced long periods of inactivity, however, and the railroad was never constructed. After a number of rather hazardous experiences, Mr. Dawley returned home in 1913.

On his return, he entered private practice as Consulting Engineer and assisted Bion J. Arnold, M. Am. Soc. C. E., in a study and report on the railroad terminals of Chicago. He made similar studies with Mr. Arnold at Flint, Mich., in 1915, and at Baltimore, Md., in 1917. In 1918, he became associated with C. E. Smith and Company, Consulting Engineers, of St. Louis, Mo., and was in charge of many problems of river freight-handling facilities as well as railroad, industrial, and civic problems.

Although more than 60 years old at the time of the World War, Mr. Dawley made application to enlist in the Army and was commissioned a Major only to have the commission rescinded immediately due to his age. He was employed by the Government, however, as Consulting Expert on the Army Base at New Orleans, La., and, later, was assigned to the United States Railroad Administration to assist in settling claims arising from the Government operation of the railroads.

Following the war, he became greatly interested in the Federal valuation of railroads. His personal connection with the original construction of many miles of railroad, coupled with his intimate and well retained knowledge of the cost, made him much in demand to present expert opinion before the Interstate Commerce Commission. It was while on an inspection trip, preparing for a railroad valuation case, that Mr. Dawley suddenly became ill on the train, and died shortly thereafter.

Mr. Dawley was particularly fond of young engineers and many of them have been made better engineers and better men by the kindly and unassuming way he had of explaining to them the problems that he had faced, as well as by the way in which he always could make clear the ethics of a situation.

That equals and superiors as well as subordinates loved him and trusted him cannot better be told than in that which has been written already by a Railroad President with whom he was associated for years:

"With his ability there is coupled a kindliness of heart and temperament that makes him particularly useful in meeting strangers and adapting himself to changing conditions, and he has ability without a display of vanity and will never offend even the poorest laborer, nor be a party to corruption no matter from what source it may arise."

Mr. Dawley was a member of the Western Society of Engineers, the St. Louis Engineers' Club, the St. Louis Railway Club, the Circle Club, and the City Club of St. Louis. He was active in the founding, and was a Charter Member, of the American Railway Engineering Association and served as the first Treasurer of that Association. holding the position from 1899 to 1909.

In 1890, Mr. Dawley was married to Angie Louise Haven. Mrs. Dawley and a daughter, Helen Louise, survive him.

Mr. Dawley was elected a Member of the American Society of Civil Engineers on October 4, 1905.

FRED ATWOOD JONES, M. Am. Soc. C. E.*

DIED MAY 22, 1928.

Fred Atwood Jones was born in Dallas, Tex., on August 23, 1875, the son of Frank Jones and Nannie E. (Hunt) Jones, natives of Missouri, his father having gone to Texas as a lumberman with the William Cameron Interests.

When the boy was three years of age the family moved to Bonham, Tex., where he was educated, having been graduated from Fannin College, at the age of fifteen. He then attended and was graduated from Richmond College, at Richmond, Va., receiving his Bachelor of Arts Degree from that institution in 1894. He then enrolled in Cornell University, at Ithaca, N. Y., to take professional courses and, in 1898, he received the degree of Electrical and Mechanical Engineer.

After his graduation from Cornell, Mr. Jones began the practice of miscellaneous engineering and surveying in Northern Texas. Later, he took the Student's Course with the General Electric Company, at Schenectady, N. Y., and for two years he was engaged in the Testing and Railway Engineering Departments of that Company.

In January, 1902, Mr. Jones opened an engineering office in Houston, Tex. He served as Consulting Engineer during the building of the power station of the Southern Pacific Terminal Company, at Galveston, Tex., as well as that of the Corsicana Gas and Electric Company, and many other such plants, at the same time submitting a great number of engineering reports. By 1908, he had gathered about him other highly efficient engineers and builders. To list his chief works would be to review the great building operations of many large centers of Texas, from the older cities to the new-born oil centers. Among other structures at Dallas that may be credited to his organization, are the Dallas Country Club; the Sumpter (now the Central Bank) Building; the Southern Methodist University Administration Building; the City Hall, which is a lasting monument of beauty and stability, comparing well with the foremost municipal buildings of the largest cities; the Southland Life Building; the eight-story addition to the Interurban Building; the White Rock Reservoir; the Dallas Filtration Plant; the Texas "Farm & Ranch" Building; the Palace Theatre, which ranks with the leading theatre buildings of America; and the interurban lines leading from Dallas to Sherman, from Dallas to Corsicana, and from Dallas to Waco.

At Houston, the Rossonian Apartments, the Sunset Hospital, the Bender Hotel, and the Levy Brothers Department Store are some of his work in that city, as well as the Telephone Exchange, which is also to his credit. There is also the American National Insurance Building, at Galveston, Tex.; the

* Memoir prepared from information on file at the Headquarters of the Society.

Nueces Hotel, at Corpus Christi, Tex.; the Paso Del Norte Hotel, at El Paso, Tex.; Trinity University Dormitory, at Waxahachie, Tex.; the National Supply Building and the Republic Supply Building, at Ranger, Tex.; the Atlas Supply Company Building, at Eastland, Tex.; and the County Hospital, the Moulton Hotel, and the American Trust and Savings Bank Building, a twenty-story structure, all at Birmingham, Ala.

In addition, Mr. Jones prepared the cost review report on the Roosevelt Dam, Salt River Valley project, which brought into usefulness land valued at $10 000 000. He also made the survey and report for the proposed Dallas-Wichita Falls Interurban Line, and his organization handled the construction of Camp McArthur cantonment, Rich Field (an aviation camp), and a large hospital for the Government, at Waco.

During the World War, he was Chairman of the Military Training Camps Association, and conducted examinations of civilians for Officers' Training Camps. He also represented the Secretary of War in visiting training camps and aviation fields in Texas and conferring with officers on various matters.

On September 5, 1910, Mr. Jones was married to Gussie Holland, the daughter of the late Col. Frank P. Holland, a former Mayor of Dallas, and the owner of *Farm & Ranch,* and *Holland's Magazine.* They had three children, Fred A. Jr., Robert Holland, and Latham Fletcher Jones. He is also survived by his brothers, the Hon. Frank C. Jones, of Houston, and C. A. Jones, of Greenville, Tex.

Although quiet and unassuming, Mr. Jones was one of the most prominent engineers and builders of the Southwest. He allied himself with the social and civic life as well as with the commercial affairs in each city in which he resided. He was a Shriner, a member of Hella Temple, Dallas, and a member of the City Club, the Dallas Country Club, and the Brook Hollow Golf Club. He was one of the oldest members of the American Institute of Electrical Engineers.

Mr. Jones was elected a Member of the American Society of Civil Engineers on December 6, 1915.

BATTLE HARGROVE KLYCE, M. Am. Soc. C. E.*

DIED MAY 23, 1928.

Battle Hargrove Klyce was born in Carpenteria, Calif., on December 10, 1882, the son of a minister of the Methodist Episcopal Church. In his early childhood his parents moved to Tennessee. His primary education was received in the public schools of the State until he became old enough to prepare for college. He then attended the Webb School for Boys at Bellbuckle, Tenn., where he studied under the famous Sawney Webb—founder of the school—who enjoyed the distinction of being one of the outstanding teachers and developers of boys' character in all the Southland. On completion of his course at the Webb School, Mr. Klyce entered Vanderbilt University, at Nashville, Tenn., enrolling in the course in Civil Engineering; he was graduated

* Memoir prepared by C. N. Harrub, M. Am. Soc. C. E.

from Vanderbilt in 1906 with the degrees of Bachelor of Arts and Bachelor of Engineering. His work in college was of the highest order, winning for him the honor of membership in Phi Beta Kappa. He also won the Founders' Medal for scholarship, the highest honor to be achieved at Vanderbilt University.

Immediately after his graduation, Mr. Klyce was employed as Assistant City Engineer of Jackson, Miss., which position he occupied for about three years, when he was made City Engineer. He held this position until January, 1911, when he became associated with Solomon and Norcross, of Atlanta, Ga., for which firm he supervised the construction of municipal improvements in several Southern cities. In 1912, he became City Engineer of Waycross, Ga., where he remained for about a year and one-half, after which he returned to private work with the late James N. Hazlehurst, M. Am. Soc. C. E., at Miami, Fla. On the completion of this engagement he was employed by the City of Miami to take charge of the design and construction of various municipal improvements, including sewers, sewage pumping station, sewage disposal works, incinerator, paving, etc. This work extended over a period of three and one-half years.

In June, 1916, Mr. Klyce became associated with W. J. Kackley, M. Am. Soc. C. E., under the firm name of Klyce and Kackley, of Nashville, Tenn., engaged in general engineering business in Florida, Georgia, Tennessee, and Arkansas. Mr. Klyce also acted as Project Engineer for the U. S. Housing Corporation for the proposed housing development at Wrigley, Tenn., and as Supervising Engineer to the Construction Quartermaster for the Aviation Gunnery School at Chapman Field, Miami.

His outstanding work was the design and construction of the Miami Causeway, a structure which extends a distance of three and one-half miles across Biscayne Bay, and which is a monument to his engineering ability.

The partnership of Klyce and Kackley was dissolved in 1920, after which Mr. Klyce continued in business in his own name for several years. In 1923, he became associated with C. N. Harrub, M. Am. Soc. C. E., later changing the firm name to Klyce and Harrub. The new firm continued in municipal engineering work, and at the time of Mr. Klyce's death, was serving many cities in Tennessee, Kentucky, and Mississippi.

In 1912 he was united in marriage to Marion Watkins, of Jackson, Miss., who, with their five children, Erskine, Battle H. Jr., Shelby, Billie, and Mary Alice, survives him.

Soon after Mr. Klyce's return to Nashville from Florida, he connected himself with the Blakemore Methodist Episcopal Church of that city, and became one of its leaders. He was Chairman of the Building Committee for the construction of the new church in 1924, and, subsequently, was also Chairman of the Finance Committee.

Mr. Klyce's varied experience in many States of the South made for him an unusually large circle of friends, as all who knew him liked him and respected him for his manliness and high Christian character. He was a member of the Engineering Association of Nashville, of which he was President in 1927. He was also a Past-President of the Nashville Local Section of

the Society. He was a member of the Nashville Automobile Club and the Lions' Club.

Mr. Klyce enjoyed the respect and esteem of his engineering colleagues, and his death is a blow to the profession which will long be felt; his associates in church and business will find his place difficult to fill.

Mr. Klyce was elected an Associate Member of the American Society of Civil Engineers on June 30, 1911, and a Member on March 9, 1920.

CHARLES KENNETH CURRY, Assoc. M. Am. Soc. C. E.*

DIED SEPTEMBER 17, 1927.

Charles Kenneth Curry was born on April 15, 1895, at Jackson, Mich., the son of the Rev. and Mrs. E. R. Curry. The family lived for a time in Jackson and also in Flint, Mich., when Mr. Curry answered a call in New Jersey. From New Jersey they went to Omaha, Nebr., where Charles Kenneth Curry was graduated from High School in 1913. He entered the University of Colorado the following September, and received the degree of Bachelor of Science in Civil Engineering in 1917.

A few months later, Mr. Curry enlisted in the Army and went to France with an artillery regiment. He served in five major engagements when his superior officers recognized his ability and he was sent to the Engineer Officers School at Langres, France. From this school he received a commission as Second Lieutenant in the Engineer Officers Reserve Corps. When the Armistice was signed he was sent into Germany with the Army of Occupation. He afterward entered the University of Nancy where he studied for four months.

On his return to the United States in September, 1919, Mr. Curry was engaged as Draftsman with the American Bridge Company at Gary, Ind., for a short time until a better opportunity was presented by the Robins Conveying Belt Company, Chicago, Ill., with which he was associated until 1921. In 1921, he was employed by Allen and Garcia Company, of Chicago, and his work with this firm, both in the office and in the field, was attended with success. He spent some time in Mexico on construction work at a coal mine. In 1927, he was sent to Price, Utah, by his Company to assist in putting into operation a coal tipple which he had designed. While engaged on this work he was stricken with appendicitis and died on September 17, 1927, following an operation.

As an engineer Mr. Curry's success seemed assured. He was only thirty-two years old at the time of his death, but he had laid an unusual foundation for his work and had accomplished that which would do credit to a much older man. He was practical and possessed as well a good working knowledge of theory. He had executive ability and men liked to work with him. He was a man of high ideals and charming personality.

On August 28, 1926, Mr. Curry was married to Mary Allen, of Chicago, who survives him. He was a member of the Hyde Park Baptist Church.

* Memoir prepared by T. E. Lutz, Esq., Chicago, Ill.

Mr. Curry was elected an Associate Member of the American Society of Civil Engineers on October 1, 1926. He was also an Associate Member of Western Society of Engineers.

LUCERN S. STEWART, Affiliate, Am. Soc. C. E.*

DIED NOVEMBER 29, 1927.

Lucern S. Stewart was born at Marshall, Ill., on May 5, 1856. He received his education in the public schools of Illinois.

Mr. Stewart's first bridge work was with the Wabash, Chester, and Western Railroad Company, in Illinois, and he was rapidly promoted to be Superintendent of Bridges.

In 1885, he was employed by the late George S. Morison, Past-President, Am. Soc. C. E., Chief Engineer, to build the caissons for the Illinois Central Railroad Bridge over the Ohio River, at Cairo, Ill. After finishing this work, Mr. Morison sent him to the Merchants Bridge, in St. Louis, Mo., then under construction. He was soon transferred in 1887, to Memphis, Tenn., and made General Foreman of Substructure on the Kansas City, Fort Scott and Memphis Railroad Bridge over the Mississippi River. The construction of this bridge extended over a period of about five years, and the experience obtained under Mr. Morison as Chief Engineer, and the late Alfred Noble, Past-President, Am. Soc. C. E., Resident Engineer, was invaluable to Mr. Stewart. When the Memphis Bridge was finished in 1892, he took charge of the substructure work on the Burlington Bridge over the Mississippi River, near St. Louis.

In 1893, Mr. Stewart entered the service of the late A. J. Tullock, M. Am. Soc. C. E., Proprietor of the Missouri Valley Bridge and Iron Works, as Superintendent on the substructure of the Missouri River Bridge, at Leavenworth, Kans., and in 1895 and 1896, he was Superintendent of the Missouri River Bridge, at Jefferson City, Mo.

In 1896, when contract work was almost at a standstill because of a financial crisis, Mr. Stewart was employed by the Kansas City, Fort Scott and Memphis Railroad Company, for which he carried on an extensive reconstruction program on bridges until August, 1898, when he again entered the service of Mr. Tullock. During the next six years he had charge of the following large substructure contracts: Reconstruction of some of the old piers on the St. Louis, Iron Mountain, and Southern Railway Bridge over the Arkansas River, at Little Rock, Ark.; the Kansas City, Pittsburgh and Gulf Railway Bridge over the Red River, at Index, Tex.; the Tampico Wharf for the Mexican Government at Tampico, Mexico; the Texas and Pacific Railway Bridge over Old River at Steamboat Island, in Louisiana; the El Paso and Southwestern Railway Bridge over the Rio Grande, near El Paso, Tex.; the Fort Smith and Western Railway Bridge over the South Canadian River, at

* Memoir prepared by William Harris Bosler, M. Am. Soc. C. E.

Garner, Indian Territory, and two bridges for the Memphis, Helena and Louisiana Railway Company (Missouri Pacific Lines) over the Arkansas and White Rivers, in Arkansas.

After the death of Mr. Tullock in 1904, the Missouri Valley Bridge and Iron Company was organized, and Mr. Stewart was made Superintendent of Construction, which position he held until December, 1906, when he resigned to organize the Union Bridge and Construction Company, of which he was made President. He continued as President of this Company until October, 1921, when he was made Chairman of the Board of Directors, which position he retained until his death.

After the organization of his own company, Mr. Stewart successfully executed a number of large substructure contracts, some of which were: The Mississippi River Bridge, at Keithburg, Ill.; two bridges at Portland, Ore., over the Willamette River; the Harahan Bridge over the Mississippi River, at Memphis, Tenn.; the Paducah and Illinois (Burlington) Bridge over the Ohio River, at Metropolis, Ill.; the New Orleans and Pacific Railway Bridge over the Atchafalaya River, in Louisiana; and two bridges for the Northern Pacific Railway Company, over the Yellowstone and Missouri Rivers, in Montana.

In 1917, when the United States Government called for contractors to build ships, Mr. Stewart accepted contracts to build six 3 500-ton hulls of the Ferris type, three cargo hulls of the 2 000-ton type, and six 5 000-ton hulls of the Daugherty type. The first nine of these hulls were successfully completed and went into service, but those of the Daugherty type were never completed, the contract having been cancelled after the signing of the Armistice.

Practically all the substructure work which Mr. Stewart executed, was done by the pneumatic process. He probably acquired more practical experience and a greater knowledge of pneumatic foundation work than any other man of his time. The base on which this experience and knowledge was founded, was ability, integrity, energy, and resourcefulness, combined with a keen foresight, and the faculty to judge men.

As evidence of the esteem in which he was held by engineers, the following is cited: In 1902, a contractor of New York City inquired of Mr. Alfred Noble the name of the best foundation man in the United States to take charge of an important piece of work. Mr. Noble replied "the name of that man is L. S. Stewart, and you will be fortunate if you can secure his services".

From Ralph Modjeski, M. Am. Soc. C. E., comes the following tribute:

"I have known Mr. Stewart for many years; my first acquaintance with him was about 36 years ago, when, as general foreman, he was in charge of building the difficult foundations of the old Memphis Bridge. Later, as head of the Union Bridge and Construction Company, he built the foundations and piers of the second Memphis or Harahan Bridge. On these important pieces of work, as well as on many others, he commanded the admiration, respect, and friendship of every one who came in contact with him. Every one recognized in him great energy, resourcefulness, thoroughness, and absolute integrity. It was often said that 'no one could knock the caisson together quicker

and better than L. S. Stewart'. One felt that within his cheerful, amiable and even disposition, dwelt an indomitable energy and honesty of purpose. Through his death the Engineering Profession and his many friends have suffered an inestimable loss."

In 1923, Mr. Stewart practically retired from active service, and moved with his family to Tampa, Fla., where he remained until his death. He is survived by a wife and one son, Mr. O. W. Stewart, of Tampa.

He was a York Rite Mason and a member of Abdallah Temple, A. A. O. N. M. S., of Leavenworth, Kans.

Mr. Stewart was elected an Affiliate of the American Society of Civil Engineers on February 6, 1912.

WILLIAM BACON WELLS, Jun. Am. Soc. C. E.*

DIED FEBRUARY 17, 1928

William Bacon Wells, the son of George William Wells and Amy Bacon Wells, was born at Lewis, Kans., on August 26, 1899. He received his Grammar and High School education at Lewis, and studied Civil Engineering at Kansas University, from which he was graduated in 1922 with the degree of Bachelor of Science in Civil Engineering.

After his graduation, Mr. Wells was engaged as Assistant City Engineer in Ellsworth, Kans. In this capacity, he acted as Resident Engineer on the construction of the water-works system in that city.

In 1923 he entered the employ of F. E. Devlin, Civil Engineer, of Wichita, Kans., and for the next two years he was Resident Engineer for the Company in charge of various municipal improvements in Caldwell, Kans., Waurika, Okla., and Englewood, Colo.

In 1925, when the Devlin Engineering Company was organized, with a branch office in Amarillo, Tex., Mr. Wells went with the writer to act as Engineer for the firm on projects in Western Texas and Eastern New Mexico. In this capacity he designed and supervised the construction of storm sewers and drainage works in Clarendon, Tex.; a sanitary sewer system in Brownfield, Tex.; water-works and sewer extensions and street paving in Portales, N. Mex.; street improvements at O'Donnel, Tex.; and street paving at Tulia, Tex. In 1927, Mr. Wells returned to Kansas to take charge of the installation of a sanitary sewer system in Cedarvale; he had completed this project a few months before his death at Clay Center, Kans.

While the foregoing account covers the work done by Mr. Wells during the short span of life allotted to him, mention should be made of some other things—the things of the spirit that remain and are even more permanent than the structures reared by this young engineer.

On completing his engineering training he chose to enter the ranks of those engineers who are fighting the battle of "Main Street"—fighting for the betterment of living conditions in the "small towns" of the Southwest. The writer recalls how, after many weary miles of driving over the plains of

*Memoir prepared by Joseph Rady, Assoc. M. Am. Soc .C. E.

Texas, he would discuss with Mr. Wells the problems of these small towns that were being built. It was not the actual construction work in itself which was found so difficult, but the earlier task of the incorporation of these new towns with all the consequent handicaps that surround such an undertaking. The struggle with the apathy and ignorance of some of the inhabitants, the opposition in promoting mass meetings, and the discussions as to whether the bonds for the sewer and water systems—those elementary necessities of civilized living—should be voted for, were only some of the obstacles encountered.

In all these things, Mr. Wells showed not only great energy and ability, but also a rare understanding of these pioneer people from whom he sprang. He loved the Southwest and its people, worked for them, and gave his life for them. He died of ptomaine poisoning, in the language of his native land, "with his boots on". He summed up his life's work aptly in closing his report to the City Commission of Clarendon, with these words: "It is our hope that this report may lead to a healthier and more beautiful Clarendon."

Mr. Wells was a member of the Delta Upsilon Fraternity and the Kansas Alumni Association.

His marriage, in June, 1925, to Norma McFadden, of Nevada, Mo., was the culmination of a romance of college days. He is survived by his widow and his parents.

Mr. Wells was elected a Junior of the American Society of Civil Engineers on March 12, 1923.

VOL. LIV

SUBJECT INDEX

Accidents
"The Engineer's Part in Making the Highway Safe." A. H. Hinkle, 2089.

Addresses
"Builders, Defenders, and Political Despoilers of Our Country": Address at the Annual Convention in Buffalo, N. Y., July 18, 1928. Lincoln Bush. 1683.

Aerial Tramways
See Cableways.

Agreements
See Contracts.

Agriculture
"The Effect of Agricultural Drainage Upon Flood Run-Off." Sherman M. Woodward and Floyd A. Nagler, 165.

Airplanes
"The Design of Airplane Wing-Beams." Joseph S. Newell, 725. Discussion: Alfred S. Niles, 2127.

Appraisal
See Valuation.

Aqueducts
The proposed Los Angeles-Colorado River Aqueduct, 1116.

Arches
"A Graphic Method for Determining the Stresses in Circular —— Under Normal Loads by the Cain Formulas." Discussion: William Cain, Walter L. Huber, Glen Edgar Edgerton, 333; Lars R. Jorgensen, 843; Fred A. Noetzli, 1531.
"Analysis of Arch Dams by the Trial Load Method." C. H. Howell and A. C. Jaquith, 61. Discussion: B. F. Jakobsen, George R. Rich, 1311; C. A. P. Turner, F. H. Constant, F. W. Hanna, 1585; L. J. Mensch, William Cain, 1879; J. L. Savage and Ivan E. Houk, Fred A. Noetzli, 2317; Fredrik Vogt, A. Floris, 2515.
"Crown Stresses in a Skew Arch." J. Charles Rathbun, 485. Discussion: B. F. Jakobsen, Edward Godfrey, 1639.
"Load Distribution in High Arch Dams." R. A. Sutherland, 1027. Discussion: William Cain, B. F. Jakobsen, 2151; Paul Bauman, A. Floris, 2387.
"Notes on Arched Gravity Dams." Discussion: Paul Bauman, William Cain, F. W. Hanna, E. W. Kramer, A. J. Wiley, W. P. Creager, Edward Godfrey, C. A. P. Turner, 220; B. F. Jakobsen, 1479.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.

Asphalt
"Economic Comparisons of Various Types of Road Surfacing." A Symposium. F. E. Everett, H. J. Kuelling, 2477.

Assessments
"County Sewer District Work in Ohio and Assessment of Cost According to Benefits." E. G. Bradbury, 2061.

Automobile Tires
"Relation of Road Type to Tire Wear." Discussion: O. L. Waller and H. E. Phelps, 583.

Automobiles
"Relation of Road Type to Tire Wear." Discussion: O. L. Waller and H. E. Phelps, 583.

Bars
"The Great Yangtze Bar." Discussion: A. W. Robinson, 327; R. L. Vaughn, 637.

Beaches
See Shore Protection.

Beams
"Continuous —— Over Three Spans." I. Oesterblom, 709. Discussion: Frank S. Bailey, 1655; Clyde T. Morris, A. Lincoln Hyde, Harold E. Wessman, Robert M. Wilder, 1961; W. F. Way, 2373; H. M. Hadley, 2559.
"Load Distribution in High Arch Dams." R. A. Sutherland, 1027. Discussion: William Cain, B. F. Jakobsen, 2151; Paul Bauman, A. Floris, 2387.
"The Design of Airplane Wing-Beams." Joseph S. Newell, 725. Discussion: Alfred S. Niles, 2127.

Bitumen
See Asphalt.

Bridges
"The Eye-Bar Cable Suspension Bridge at Florianopolis, Brazil." Discussion: Hardy Cross, 579; D. B. Steinman and William G. Grove, 1133.
"The Stiffness of Suspension ——." S. Timoshenko, 1464. Discussion: Lloyd G. Frost, Hans H. Rode, 2405; E. Steuermann and George C. Priester, 2737.

Buildings
"Effect of Earth Shocks on Structures." M. de Bussey, 1449. Discussion: Rudolf Briske, Harry O. Wood, R. R. Martel, 2601.
"The Design of Tall Building Frames to Resist Wind." Albert W. Ross, Jr. and Clyde T. Morris, 1395. Discussion: David C. Coyle, Albert Smith, Robins Fleming, Everett E. Ebling, 2393.
"Unusual Engineering Features of an Immense Theatre Building." Discussion: Theodore Belzner, Fred A. Noetzli, 1579; A. Floris, Laurence J. Waller, R. McC. Beanfield, 2119.

Buses, Motor
See Motor Buses.

Cables
"The Eye-Bar Cable Suspension Bridge at Florianopolis, Brazil." Discussion: Hardy Cross, 579; D. B. Steinman and William G. Grove, 1133.
"The Stiffness of Suspension Bridges. S. Timoshenko, 1464. Discussion: Lloyd G. Frost, Hans H. Rode, 2405; E. Steuermann and George C. Priester, 2737.

Cableways
"Aerial Tramways." Discussion: Robert C. Strachan, 359; George Paaswell, Casper D. Meals, 847.

Camps
"Builders, Defenders, and Political Despoilers of Our Country": Address at

the Annual Convention in Buffalo, N. Y., July 18, 1928. Lincoln Bush. 1683.

Canals
"Emergency Dam on Inner Navigation Canal at New Orleans, Louisiana." Discussion: F. R. Harris, R. H. Whitehead, 673; R. O. Comer, W. J. Barden, Roger D. Black, Samuel McC. Young, 1273; T. B. Mönniche, 1569.
"Side Spillways for Regulating Diversion ——." Discussion: Edward S. Lindley, 641; A. P. Flockart, George M. Bacon, 1527.
"The Head-Works of the Imperial Canal." Discussion: E. S. Lindley, 2103.
"The Isthmian Canal Situation." Hans Kramer, 1693.
"The Lake Washington Ship Canal, Washington." Discussion: L. C. Sabin, 273; W. J. Barden and A. W. Sargent, 585.

Cantonments
See Camps.

Cement
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.

Centrifugal Pumps
See Pumps.

City Planning
"Base Maps for Regional Planning." Harland Bartholomew, 1745.
"Basic Information Needed for a Regional Plan." Discussion: Harland Bartholomew, 289; Donald M. Baker, Harry J. March, 597; Harold M. Lewis, 1165.
"Cultural Opportunities in Regional Planning." Discussion: Charles W. Eliot, 2d, Winters Haydock, Gilmore D. Clarke, Harry J. March, 601; John Ihlder, Joseph Barnett, 823.
"Engineering Applied to National Parks." Stephen T. Mather, 2673.
"Forecast: The Regional Community of the Future." Discussion: Morris Knowles, 291; Thomas Adams, 1169.
"Housing and the Regional Plan." Discussion: John Ihlder, 821.
"Imagination in ——." Stephen Child, 1009. Discussion: W. W. Crosby, Arthur A. Shurtleff, 2147; R. D. N. Simham, M. W. Weir, 2409.
"Relation of the Landscape Architect to the Allied Professions Engaged in ——." Arthur A. Shurtleff, 2667.
"Standard City Engineering Surveys." Robert H. Randall, 1749.
"Street Designing for Various Uses." George William Tillson, 1725. Discussion: Harold M. Lewis, W. W. Crosby, W. C. Sawyer, William C. Reeder, William T. Lyle, 2611.
"The Planning of the Industrial City of Longview, Washington." Discussion: Brookes Baker, S. Herbert Hare, 815.

Coast
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.
"Surveys on the —— of New Jersey." Discussion: C. V. Hodgson, 345.

Columns
"A Proposed Formula for ——." T. F. Hickerson, 1435. Discussion: William R. Osgood, 2401; Henry S. Prichard, E. H. Salmon, C. N. Ross, K. L. DeBlois, Edward Godfrey, 2721.

Commerce
"The Delaware River from Philadelphia to the Sea." Discussion: Harry Taylor, F. C. Warner, 347; William Gerig, F. C. Boggs, 1537.

Concrete
"—— Pavement Over Poor Sub-Grade at Port Newark, New Jersey." Chester Mueller, 2045.
"Continuous Beams Over Three Spans." I. Oesterblom, 709. Discussion: Frank S. Bailey, 1655; Clyde T. Morris, A. Lincoln Hyde, Harold E. Wessman, Robert M. Wilder, 1961; W. F. Way, 2373; H. M. Hadley, 2559.
"Design and Construction of —— Pavements." Clifford Older, 147. Discussion: R. T. Giles, Elmer G. Hooper, 917; G. E. Hawthorn, H. O. Root, 1617; D. P. Krynine, 1913.
"Economic Comparisons of Various Types of Road Surfacing": A Symposium, F. E. Everett, H. J. Kuelling, 2477.
"Methods Used in the Construction of Twelve Pre-Cast —— Segments for the Alameda County, California, Estuary Subway." Discussion: Joseph A. Kitts, 1287.
"Problems in —— Dam Construction on the Pacific Coast." Discussion: R. A. Hill, 827; Fred A. Noetzli, 1509.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.

Contracts
"General Contract System Versus Segregated ——." Ward P. Christie, 395. Discussion: Edward W. Bush, William T. Lyle, B. F. Jakobsen, 1319; C. C. Muhs, W. J. Barney, Lazarus White, L. S. Stiles, Gustave R. Tuska, T. Kennard Thomson, H. M. Dougherty, 1623; W. A. Starrett, Robert Ridgway, R. E. Bakenhus, Wilson T. Ballard, 1921.
"Letting Construction Work by Competitive Bidding." Edward W. Bush, 2437.
"Qualifications of Contractors on Public Works." Frank T. Sheets, 1021. Discussion: Ralph F. Proctor, Walter S. Anderson, Morris Knowles, H. C. Boyden, T. Chalkley Hatton, 2005.

Costs of Work
"General Contract System Versus Segregated Contracts." Ward P. Christie, 395. Discussion: Edward W. Bush, William T. Lyle, B. F. Jakobsen, 1319; C. C. Muhs, W. J. Barney, Lazarus White, L. S. Stiles, Gustave R. Tuska, T. Kennard Thomson, H. M. Dougherty, 1623; W. A. Starrett, Robert Ridgway, R. E. Bakenhus, Wilson T. Ballard, 1921.
"Letting Construction Work by Competitive Bidding." Edward W. Bush, 2437.
"The Role of the Civil Engineer in Power Development." I. W. McConnell, 155. Discussion: P. Junkersfeld, George A. Orrok, Joel D. Justin, F. W. Scheidenhelm, 923; J. A. Sargent, 1917.

Currents
See Ocean Currents.

Dams
"A Graphic Method for Determining the Stresses in Circular Arches Under Normal Loads by the Cain Formulas." Discussion: William Cain, Walter L. Huber, Glen Edgar Edgerton, 333; Lars R. Jorgensen, 843; Fred A. Noetzli, 1531.

"Analysis of Arch —— by the Trial Load Method." C. H. Howell and A. C. Jaquith, 61. Discussion: B. F. Jakobsen, George R. Rich, 1311; C. A. P. Turner, F. H. Constant, F. W. Hanna, 1585; L. J. Mensch, William Cain, 1879; J. L. Savage and Ivan E. Houk, Fred A. Noetzli, 2317; Fredrik Vogt, A. Floris, 2515.
"Baffle-Pier Experiments on Models of Pit River ——." Discussion: Edward C. Sherman, 363; B. E. Torpen, Oren Reed, Harold K. Fox, 857; Robert F. Ewald, F. W. Scheidenhelm, 1225; Ralph L. Parshall, H. W. Dennis, I. A. Winter, 1549; Paul Bauman, Morrough P. O'Brien, 1807; J. C. Stevens, 2303.
Bibliography on arch and multiple-arch ——. May, Pt. 3, 277.
Bibliography on load distribution in high arch ——. 1068.
"Emergency Dam on Inner Navigation Canal at New Orleans, Louisiana." Discussion: F. R. Harris, R. H. Whitehead, 673; R. O. Comer, W. J. Barden, Roger D. Black, Samuel McC. Young, 1273; T. B. Mönniche, 1569.
"Load Distribution in High Arch ——." R. A. Sutherland, 1027. Discussion: William Cain, B. F. Jakobsen, 2151; Paul Bauman, A. Floris, 2387.
"Notes on Arched Gravity ——." Discussion: Paul Bauman, William Cain, F. W. Hanna, E. W. Kramer, A. J. Wiley, W. P. Creager, Edward Godfrey, C. A. P. Turner, 220; B. F. Jakobsen, 1479.
"Problems in Concrete Dam Construction on the Pacific Coast." Discussion: R. A. Hill, 827; Fred A. Noetzli, 1509.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.
"The Conowingo Hydro-Electric Development on the Susquehanna River." Discussion: H. A. Hageman, 667.
"The Lake Washington Ship Canal, Washington." Discussion: L. C. Sabin, 273; W. J. Barden and A. W. Sargent, 585.
"The O'Shaughnessy Dam and Reservoir." John H. Gregory, C. B. Hoover and C. B. Cornell, 405. Discussion: J. Ernest Carman, B. F. Jakobsen, 1325; W. H. Dittoe, G. Gale Dixon, 1635.
"Upward Pressures Under ——: Experiments by the United States Bureau of Reclamation." Julian Hinds, 685. Discussion: E. L. Chandler, 1349; B. F. Jakobsen, 1653; Charles Terzaghi, J. C. Stevens, F. W. Hanna, 1953; Ivan E. Houk, C. H. Howell, P. Wilhelm Werner, H. de B. Parsons, 2345.

Dikes

"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"The Delaware River from Philadelphia to the Sea." Discussion: Harry Taylor, F. C. Warner, 347; William Gerig, F. C. Boggs, 1537.

Drainage

"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"Flood Control with Special Reference to the Mississippi River": A Symposium. Discussion: J. P. Snow, Frank B. Maltby, Morris Knowles, Charles H. Paul, F. G. Jonah, 185; C. S. Jarvis, Edward H. Schulz, Q. C. Ayres, H. S. Gladfelter, Byron E. White, 881; W. G. Price, Oren Reed, Harold C. Fiske, Charles F. Brooks, William Gerig, C. H. Eiffert, Sherman M. Woodward, 1253; W. J. Schlick, 1565; S. L. Moyer, William M. Hall, C. E. Ramser, T. Kennard Thomson, 1843; W. E. Elam, R. W. Davenport, E. W. Lane, 2685.
"Foundations and —— of Highways." Albert C. Rose, 123. Discussion: Harry Tucker, Winslow H. Herschel, 913; Charles Terzaghi, D. P. Krynine, 1909.
"Return Water and —— Recovery from Irrigation." A. Symposium. R. H. Willis, D. W. Murphy, 1097. Discussion: R. I. Meeker, Fred H. Tibbetts, 2187.
"The Effect of Agricultural —— Upon Flood Run-Off." Sherman M. Woodward and Floyd A. Nagler, 165.

Dredging

"Advances in Waterways Engineering During a Half Century." Discussion: C. L. Hall, DeWitt D. Barlow, 643; W. M. Black, 2101.
"The Delaware River from Philadelphia to the Sea." Discussion: Harry Taylor, F. C. Warner, 347; William Gerig, F. C. Boggs, 1537.
"The Great Yangtze Bar." Discussion: A. W. Robinson, 327; R. L. Vaughn, 637.

Dynamometers

"Hydrostatic Uplift in Pervious Soils." H. de B. Parsons, 941. Discussion: F. R. Harris, J. C. Meem, Eugene E. Halmos, T. R. Lawson, J. Vipond Davies, Lazarus White, T. Kennard Thomson, Daniel E. Moran, Alexander V. Gallogly, Allen Hazen, Charles Terzaghi, Frank S. Bailey, Charles R. Gow, E. L. Chandler, 1971; Martin J. McPike, Jacob Feld, 2377; J. Albert Holmes, E. W. Lane, 2707.

Earth Pressures

"Hydrostatic Uplift in Pervious Soils." H. deB. Parsons, 941. Discussion: F. R. Harris, J. C. Meem, Eugene E. Halmos, T. R. Lawson, J. Vipond Davies, Lazarus White, T. Kennard Thomson, Daniel E. Moran, Alexander V. Gallogly, Allen Hazen, Charles Terzaghi, Frank S. Bailey, Charles R. Gow, E. L. Chandler, 1971; Martin J. McPike, Jacob Feld, 2377; J. Albert Holmes, E. W. Lane, 2707.
"The Compressibility of Sand-Mica Mixtures." Glennon Gilboy, 555; R. D. N. Simham, William W. Rubey, 1933; Jacob Feld, 2357; D. P. Krynine, 2543.
"The Science of Foundations—Its Present and Future." Discussion: Charles R. Gow, E. P. Goodrich, Victor A. Endersby, 375; George Paaswell, C. C. Williams, Herbert Chatley, 655; J. Albert Holmes, Jacob Feld, 871; W. S. Housel, Frank S. Bailey, 1243; T. L. Condron, 1561; Lazarus White, R. D. N. Simham, Frank A. Marston, 1821; Arthur M. Shaw, 2313; D. P. Krynine, 2505.

Earthquakes

——, ice, and deterioration of concrete. May, Pt. 3, 267.

"Effect of Earth Shocks on Structures." M. de Bussy, 1449. Discussion: Rudolf Briske, Harry O. Wood, R. R. Martel, 2601.
"The Relation Between —— and Engineering Substructures." Henry D. Dewell, 1737. Discussion: Walter E. Spear, M. M. O'Shaughnessy, Bailey Willis, 2749.

Economics
"Economic Comparisons of Various Types of Road Surfacing." A Symposium. F. E. Everett, H. J. Kuelling, 2477.

Electric Locomotives
—— in use on the Virginian Railway. 44.

Electric Power
"The Virginian Railway Electrification." George Gibbs, 3. Discussion: W. B. Potter, Marcel Japiot, L. K. Sillcox, I. Ofverholm, Ralph Budd, Guido Semenza, F. H. Shepard, E. R. Hill, Norman Litchfield, Sidney Withington, George J. Ray, 1295; John P. Hogan, 1581; R. D. N. Simham, 1875; George Gibbs, 2701.

Electric Railways
"The Virginian Railway Electrification." George Gibbs, 3. Discussion: W. B. Potter, Marcel Japiot, L. K. Sillcox, I. Ofverholm, Ralph Budd, Guido Semenza, F. H. Shepard, E. R. Hill, Norman Litchfield, Sidney Withington, George J. Ray, 1295; John P. Hogan, 1581; R. D. N. Simham, 1875; George Gibbs, 2701.

Electric Transmission
See Power Transmission.

Employment
"The Role of the Civil Engineer in Power Development." I. M. McConnell, 155. Discussion: P. Junkersfeld, George A. Orrok, Joel D. Justin, F. W. Scheidenheim, 923; J. A. Sargent, 1917.

Engineering
"Builders, Defenders, and Political Despoilers of Our Country": Address at the Annual Convention in Buffalo, N. Y., July 18, 1928. Lincoln Bush, 1683.
"—— Applied to National Parks." Stephen T. Mather, 2673.
"One Hundred Fifty Years Advance in Structural Analysis." H. M. Westergaard, 993. Discussion: S. Timoshenko, Alfred D. Flinn, Jacob Feld, 2383.
"The Role of the Civil Engineer in Power Development." I. W. McConnell, 155. Discussion: P. Junkersfeld, George A. Orrok, Joel D. Justin, F. W. Scheidenheim, 923; J. A. Sargent, 1917.

Erosion
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.

Eye-Bars
"The Eye-Bar Cable Suspension Bridge at Florianopolis, Brazil." Discussion: Hardy Cross, 579; D. B. Steinman and William G. Grove, 1133.

Finance
Administration of stream flow. 1085.
Financing and constructing the experimental arch dam. May, Pt. 3, 43.
"Some Phases of Irrigation Financing." Discussion: D. C. Henny, 267.

Floods
"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"Flood Control with Special Reference to the Mississippi River": A Symposium. Discussion: J. P. Snow, Frank B. Maltby, Morris Knowles, Charles H. Paul, F. G. Jonah, 185; C. S. Jarvis, Edward H. Schulz, Q. C. Ayres, H. S. Gladfelter, Byron E. White, 881; W. G. Price, Oren Reed, Harold C. Fiske, Charles F. Brooks, William Gerig, C. H. Eiffert, Sherman M. Woodward, 1253; W. J. Schlick, 1565; S. L. Moyer, William M. Hall, C. E. Ramser, T. Kennard Thomson, 1843; W. E. Elam, R. W. Davenport, E. W. Lane, 2685.
"Hydraulic Studies and Operating Results on the Miami Flood Control System." C. H. Eiffert, 1371. Discussion: C. S. Bennett, Morris Knowles, Walter M. Smith, 2017; B. F. Jakobsen, 2415.
"Maximum Flood Discharge in San Joaquin Valley, California." Discussion: Robert Follansbee, Harold K. Fox, 651; Charles H. Lee, 1235; Oren Reed, 2107.
"Probability of Flood Flows." Discussion: Ralph R. Randell, 205; F. G. Switzer, 803.
Progress Report of Special Committee on Flood-Protection Data. Discussion: Gerard H. Matthes, F. G. Switzer, Harrison P. Eddy, C. E. Grunsky, Arthur E. Morgan, Arthur N. Talbot, A. J. Hammond, William Bowie, John R. Freeman, 1657; Charles A. Pohl, 2199.
"The Effect of Agricultural Drainage Upon Flood Run-Off." Sherman M. Woodward and Floyd A. Nagler, 165.

Flumes
"Side Spillways for Regulating Diversion Canals." Discussion: Edward S. Lindley, 641; A. P. Flockart, George M. Bacon, 1527.
"The Hydraulic Design of Flume and Siphon Transitions." Discussion: F. Theodore Mavis, W. H. R. Nimmo, Carl Rohwer, 1195.

Foundations
"Concrete Pavement Over Poor Sub-Grade at Port Newark, New Jersey." Chester Mueller, 2045.
"—— and Drainage of Highways." Albert C. Rose, 123. Discussion: Harry Tucker, Winslow H. Herschel, 913; Charles Terzaghi, D. P. Krynine, 1909.
"Hydrostatic Uplift in Pervious Soils." H. deB. Parsons, 941. Discussion: F. R. Harris, J. C. Meem, Eugene E. Halmos, T. R. Lawson, J. Vipond Davies, Lazarus White, T. Kennard Thomson, Daniel E. Moran, Alexander V. Gallogly, Allen Hazen, Charles Terzaghi, Frank S. Bailey, Charles R. Gow, E. L. Chandler, 1971; Martin J. McPike, Jacob Feld, 2377; J. Albert Holmes, E. W. Lane, 2707.
"The Compressibility of Sand-Mica Mixtures." Glennon Gilboy, 555; R. D. N. Simham, William W. Rubey, 1933; Jacob Feld, 2357; D. P. Krynine, 2543.
"The Relation Between Earthquakes and Engineering Substructures." Henry D. Dewell, 1737. Discussion: Walter E. Spear, M. M. O'Shaughnessy, Bailey Willis, 2749.
"The Science of Foundations—Its Present and Future." Discussion: Charles R. Gow, E. P. Goodrich, Victor A. Enders-

by, 375; George Paaswell, C. C. Williams, Herbert Chatley, 655; J. Albert Holmes, Jacob Feld, 871; W. S. Housel, Frank S. Bailey, 1243; T. L. Condron, 1561; Lazarus White, R. D. N. Simham, Frank A. Marston, 1821; Arthur M. Shaw, 2313; D. P. Krynine, 2505.
"Upward Pressures Under Dams; Experiments by the United States Bureau of Reclamation." Julian Hinds, 685. Discussion: E. L. Chandler, 1349; B. F. Jakobsen, 1653; Charles Terzaghi, J. C. Stevens, F. W. Hanna, 1953; Ivan E. Houk, C. H. Howell, P. Wilhelm Werner, H. de B. Parsons, 2345.

Frameworks
"The Design of Tall Building Frames to Resist Wind." Albert W. Ross, Jr., and Clyde T. Morris, 1395. Discussion: David C. Coyle, Albert Smith, Robins Fleming, Everett C. Ebling, 2393.

Frequency Curves
"Probability of Flood Flows." Discussion: Ralph R. Randell, 205; F. G. Switzer, 803.

Geology
"The O'Shaughnessy Dam and Reservoir." John H. Gregory, C. B. Hoover and C. B. Cornell, 405. Discussion: J. Ernest Carman, B. F. Jakobsen, 1325; W. H. Dittoe, G. Gale Dixon, 1635.

Girders
"Continuous Beams Over Three Spans." I. Oesterblom, 709. Discussion: Frank S. Bailey, 1655; Clyde T. Morris, A. Lincoln Hyde, Harold E. Wessman, Robert M. Wilder, 1961; W. F. Way, 2373; H. M. Hadley, 2559.

Gravel
"Economic Comparisons of Various Types of Road Surfacing." A Symposium. F. E. Everett, H. J. Kuelling, 2477.

Ground Water
"Return Water and Drainage Recovery from Irrigation." A Symposium. R. H. Willis, D. W. Murphy, 1097. Discussion: R. I. Meeker, Fred H. Tibbetts, 2187.

Highways
"Economic Comparisons of Various Types of Road Surfacing." A Symposium. F. E. Everett, H. J. Kuelling, 2477.
"Foundations and Drainage of ——." Albert C. Rose, 123. Discussion: Harry Tucker, Winslow H. Herschel, 913; Charles Terzaghi, D. P. Krynine, 1909.
"Street Designing for Various Uses." George William Tillson, 1725. Discussion: Harold M. Lewis, W. W. Crosby, W. C. Sawyer, William C. Reeder, William T. Lyle, 2611.
"The Engineer's Part in Making the Highway Safe." A. H. Hinkle, 2089.
"The Practical Utility of Highway Transport Surveys." G. F. Schlesinger, 2073. Discussion: R. H. Simpson, W. A. Van Duzer, C. R. Thomas, Jr., 2755.
"Traffic Control by Electric Signal Lights." Discussion: Lewis M. McIntyre, 1217; M. O. Eldridge, 1541.
"Traffic Control in New York, N. Y." Discussion: Russell S. Wise, C. D. Curtiss, E. P. Goodrich, 1221.
See also Pavement: Roads.

Housing
"—— and the Regional Plan." Discussion: John Ihlder, 821.

Hydraulics
See Water, Flow of.

Hydro-Electric Power Plants
See Power Plants.

Ice
Earthquakes, ——, and deterioration of concrete. May, Pt. 3, 267.

Industrial Waste
"—— Disposal." A Symposium. Discussion: George W. Fuller, Almon L. Fales, 311; Edmund B. Besselievre, 615.
"The Sewage Disposal Works of Decatur, Illinois." Samuel A. Greeley and William D. Hatfield, 2237.

Irrigation
"Administrative Water Problems." A Symposium. G. Clyde Baldwin, Edward Hyatt, George M. Bacon, 1079. Discussion: M. C. Hinderlider, R. I. Meeker, Lynn Crandall, E. B. Debler, 2177; Thomas R. Newell, 2577.
"Evaluation of Water Rights." John E. Field, 1071. Discussion: Joseph Jacobs, Fred H. Tibbetts, Charles R. Hedke, Fred C. Scobey, Lyman E. Bishop, R. L. Parshall, 2157.
Report of the Committee of the —— Division on A National Reclamation Policy. J. B. Lippincott, G. M. Bacon, W. H. Code, J. A. Elliott, John E. Field, C. E. Grunsky, M. C. Hinderlider, Burton Smith, G. E. P. Smith, J. C. Stevens, R. K. Tiffany, 2097.
Report of the Committee of the —— Division on Drainage of Irrigated Lands. Discussion: M. R. Lewis, 2203.
Report of the Duty of Water Committee of the —— Division on the Consumptive Use of Water in ——. Discussion: Harold Conkling, 2207.
"Return Water and Drainage Recovery from ——." A Symposium. R. H. Willis, D. W. Murphy, 1097. Discussion: R. I. Meeker, Fred H. Tibbetts, 2187.
"Some Phases of —— Financing." Discussion: D. C. Henny, 267.
"State Reclamation in Washington." Discussion: R. K. Tiffany, 581.
"Trans-Mountain Diversions." A Symposium. E. B. Debler, H. A. Van Norman, Robert Follansbee, 1109. Discussion: A. Lincoln Fellows, Ralph Bennett, 2195; B. F. Jakobsen, Paul M. Entenman, 2581.
"Water Supply Problems of a Desert Region." William E. Rudolph, 2287.

Jetties
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent. Augustus Smith, Victor Gelineau, 2329.

Locomotives
Electric —— in use on the Virginian Railway. 44.

Maps
"Base —— for Regional Planning." Harland Bartholomew, 1745.
"Horizontal Control in Surveying": Preliminary Report of the Committee of the Surveying and Mapping Division on Horizontal Control. George L. Hosmer, 2491.
"Surveying and Mapping in the United States." Discussion: T. P. Pendleton, C. L. Hall, 339; John C. H. Lee, 845; C. H. Birdseye, 1535.

Masonic Temples
"Unusual Engineering Features of an Immense Theatre Building." Discussion: Theodore Belzner, Fred A. Noetzli, 1579; A. Floris, Laurence J. Waller, R. McC. Beanfield, 2119.

Materials of Construction
"One Hundred Fifty Years Advance in Structural Analysis." H. M. Westergaard, 993. Discussion: S. Timoshenko, Alfred D. Flinn, Jacob Feld, 2383.

Memoirs
Adams, Frederick Baird. 2040.
Adams, Henry Sewall. 2765.
Allison, James Ekin. 379.
Archibald, Warren Martin. 1671.
Aylett, Philip. 1675.
Barnes, Thomas Howard. 931.
Barr, John Toner. 2621.
Bayly, Howard Paul. 2634.
Beahan, Willard. 2023.
Blunt, William Titcomb. 2622.
Boynton, George Herbert. 2767.
Bremner, George Hampton. 2419.
Carpenter, George Ansel. 1672.
Clifford, Walter Woodbridge. 2624.
Colnon, Redmond Stephen. 677.
Crane, Clarence Austin. 2025.
Curry, Charles Kenneth. 2776.
Dawley, William Sanborn. 2770.
Eastham, Robert Francis. 933.
Edwards, Guy Banker. 2427.
Emerson, George Dana. 380.
Ericson, John Ernst. 1359.
Felt, Charles Frederick Wilson. 2626.
Flagg, Josiah Foster. 2219.
Fletcher, Austin Bradstreet. 2220.
Giesting, Frank Alexander. 2231.
Goethals, George Washington. 2223.
Going, Alvah Seymour. 2421.
Goodell, John Milton. 391.
Green, Hubert Edward. 678.
Hammatt, Edward Augustus White. 382.
Heyworth, James Ormerod. 2422.
Hosmer, Guy Frederic. 1364.
Hubbard, Frank James. 2628.
Jones, Fred Atwood. 2773.
Kennedy, James Henry. 2026.
Klyce, Battle Hargrove. 2774.
Lally, John Michael. 680.
Leavitt, Charles Wellford. 2228.
Leckliter, Walter Harlan. 2233.
Levy, Alfred. 2635.
McMinn, Thomas James. 1360.
Maitland, Alexander, Jr. 383.
Marvin, Frank Olin. 385.
Maxson, Frank Oscar. 2029.
Midolo, Mario John. 2041.
Nagle, James C. 2230.
Nauman, George. 2630.
Onstott, Virgil Samms. 2428.
O'Reilly, John Devereux. 934.
Perkins, Frank William. 388.
Riggs, Morris John. 2031.
Rose, John Gansovertte. 2429.
Rose, Rudolf Viedt. 2424.
Rosecrans, Merle William. 935.
Scofield, Glenn Mason. 2033.
Sheridan, Howard Augustus. 681.
Sleight, Reuben Benjamin. 1365.
Snyder, Hunter Imboden. 1677.
Spencer, John Clark. 389.
Spooner, Allen Newhall. 936.
Stewart, Lucern S. 2777.
Strickland, Kirby Lee. 2034.
Tallman, Paul Bertram. 2425.
Tate, Robert L'Hommedieu. 1674.
Thorndike, Sturgis Hooper. 2631.
Tillman, Frank Andrew. 2432.
Tripp, Oscar Holmes. 679.
Wagner, Frank. 1678.
Warner, Edwin Hall. 2036.
Wells, William Bacon. 2779.
Wheeler, Bertrand Thorp. 2038.
Wheeler, Levi Lockwood. 1362.

Meters
"Chemical-Electric Measurement of Water." A. Barbagelata, 789.

Models
Test of a celluloid model of the Stevenson Creek Dam. May, Pt. 3, 219.
Tests on —— at Boulder, Colorado. May, Pt. 3, 215.

Moments
"Continuous Beams Over Three Spans." I. Oesterblom, 709. Discussion: Frank S. Bailey, 1655; Clyde T. Morris, A. Lincoln Hyde, Harold E. Wessman, Robert M. Wilder, 1961; W. F. Way, 2373; H. M. Hadley, 2559.
"The Design of Airplane Wing-Beams." Joseph S. Newell, 725. Discussion: Alfred S. Niles, 2127.

Motor Buses
"The Relation of Highway Transportation to the Railway." Discussion: Ralph Budd, 1153.

Motor Trucks
"The Relation of Highway Transportation to the Railway." Discussion: Ralph Budd, 1153.

Ocean Currents
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.
"Tides and Their Engineering Aspects." Discussion: F. W. Scheidenhelm, Charles H. Lee and Harold F. Gray, 209; G. T. Rude, 807.

Ocean Waves
See Waves.

Pavement
"Concrete —— Over Poor Sub-Grade at Port Newark, New Jersey." Chester Mueller, 2045.
"Design and Construction of Concrete Pavements." Clifford Older, 147. Discussion: R. T. Giles, Elmer G. Hooper, 917; G. E. Hawthorn, H. O. Root, 1617; D. P. Krynine, 1913.
"Economic Comparisons of Various Types of Road Surfacing." A Symposium. F. E. Everett, H. J. Kuelling, 2477.
"Foundations and Drainage of Highways." Albert C. Rose, 123. Discussion: Harry Tucker, Winslow H. Herschel, 913; Charles Terzaghi, D. P. Krynine, 1909.
"Relation of Road Type to Tire Wear." Discussion: O. L. Waller and H. E. Phelps, 583.

Pipe Lines
"Water Supply Problems of a Desert Region." William E. Rudolph, 2287.

Power Plants
Bibliography on pumped-storage hydroelectric plants. 2475.
"Pumped-Storage Hydro-Electric Plants." William W. K. Freeman, 2457.
"Re-Designing Catawba Station for Service on a Large Transmission System." Discussion: H. V. Joslin, T. H. Hogg, 371.
"The Conowingo Hydro-Electric Development on the Susquehanna River." Discussion: H. A. Hageman, 667.
"The Role of the Civil Engineer in Power Development." I. W. McConnell, 155. Discussion: P. Junkersfeld, George A. Orrok, Joel D. Justin, F. W. Scheidenhelm, 923; J. A. Sargent, 1917.
"The Virginian Railway Electrification." George Gibbs, 3. Discussion: W. B. Potter, Marcel Japiot, L. K. Sillcox, I. Ofverholm, Ralph Budd, Guido Semenza, F. H. Shepard, E. R. Hill, Norman Litchfield, Sidney Withington,

George J. Ray, 1295; John P. Hogan, 1581; R. D. N. Simham, 1875; George Gibbs, 2701.

Power Transmission
"Re-Designing Catawba Station for Service on a Large Transmission System." Discussion: H. V. Joslin, T. H. Hogg, 371.
"The Role of the Civil Engineer in Power Development." I. W. McConnell, 155. Discussion: P. Junkersfeld, George A. Orrok, Joel D. Justin, F. W. Scheidenhelm, 923; J. A. Sargent, 1917.
"The Virginian Railway Electrification." George Gibbs, 3. Discussion: W. B. Potter, Marcel Japiot, L. K. Sillcox, I. Ofverholm, Ralph Budd, Guido Semenza, F. H. Shepard, E. R. Hill, Norman Litchfield, Sidney Withington, George J. Ray, 1295; John P. Hogan, 1581; R. D. N. Simham, 1875; George Gibbs, 2701.

Pressures
See Earth Pressures: Water Pressures.

Pumps
"Characteristics of Centrifugal Oil Pump." Michael D. Aisenstein, 1709.
"New Theory for the Centrifugal Pump." Discussion: Max M. Munk, Elmo G. Harris, O. Gruenberger, 317; Elmer G. Hooper, 621; F. Theodore Mavis, 831; Mario Medici, A. H. Blaisdell, Morrough P. O'Brien, 1177; R. T. Liddicoat, Lloyd H. Donnell, S. Timoshenko, 1511; A. B. Cox, 1801.
"Pumped-Storage Hydro-Electric Plants." William W. K. Freeman, 2457.

Railroads
"The Relation of Highway Transportation to the Railway." Discussion: Ralph Budd, 1153.
"The Virginian Railway Electrification." George Gibbs, 3. Discussion: W. B. Potter, Marcel Japiot, L. K. Sillcox, I. Ofverholm, Ralph Budd, Guido Semenza, F. H. Shepard, E. R. Hill, Norman Litchfield, Sidney Withington, George J. Ray, 1295; John P. Hogan, 1581; R. D. N. Simham, 1875; George Gibbs, 2701.

Rainfall
"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"Flood Control with Special Reference to the Mississippi": A Symposium. Discussion: J. P. Snow, Frank B. Maltby, Morris Knowles, Charles H. Paul, F. G. Jonah, 185; C. S. Jarvis, Edward H. Schulz, Q. C. Ayres, H. S. Gladfelter, Byron E. White, 881; W. G. Price, Oren Reed, Harold C. Fiske, Charles F. Brooks, William Gerig, C. H. Eiffert, Sherman M. Woodward, 1253; W. J. Schlick, 1565; S. L. Moyer, William M. Hall, C. E. Ramser, T. Kennard Thomson, 1843; W. E. Elam, R. W. Davenport, E. W. Lane, 2685.
"Hydraulic Studies and Operating Results on the Miami Flood Control System." C. H. Eiffert, 1371. Discussion: C. S. Bennett, Morris Knowles, Walter M. Smith, 2017; B. F. Jakobsen, 2415.
"Maximum Flood Discharge in San Joaquin Valley, California." Discussion: Robert Follansbee, Harold K. Fox, 651; Charles H. Lee, 1235; Oren Reed, 2107.
"Probability of Flood Flows." Discussion: Ralph R. Randell, 205; F. G. Switzer, 803.
"The Effect of Agricultural Drainage Upon Flood Run-Off." Sherman M. Woodward and Floyd A. Nagler, 165.

Refuse Disposal
"The Sewage Disposal Works of Decatur, Illinois." Samuel A. Greeley and William D. Hatfield, 2237.

Reports of Committees
Final Report of the Committee of the Structural Division on Florida Hurricane. H. G. Balcom, D. C. Coyle, F. R. McMillan, Lee H. Miller, Clyde T. Morris, 1757. Discussion: F. O. Dufour, T. L. Condron, 2619.
"Horizontal Control in Surveying": Preliminary Report of the Committee of the Surveying and Mapping Division on Horizontal Control. George L. Hosmer, 2491.
Progress Report of Special Committee on Flood-Protection Data. Discussion: Gerard H. Matthes, F. G. Switzer, Harrison P. Eddy, C. E. Grunsky, Arthur E. Morgan, Arthur N. Talbot, A. J. Hammond, William Bowie, John R. Freeman, 1657; Charles A. Pohl, 2199.
Progress Report of the Committee of the Sanitary Engineering Division on Filtering Materials for Water and Sewage Works. Discussion: J. W. Armstrong, Harry N. Jenks, J. N. Chester, 2213.
Report of Committee of Engineering Foundation on Arch Dam Investigation. Charles D. Marx, Fred A. Noetzli, Paul Bailey, C. Derleth, Jr., H. W. Dennis, A. D. Flinn, H. Hawgood, D. C. Henny, M. M. O'Shaughnessy, H. Hobart Porter, J. L. Savage, F. E. Weymouth, S. H. Woodard, May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. J. B. Lippincott, G. M. Bacon, W. H. Code, J. A. Elliott, John E. Field, C. E. Grunsky, M. C. Hinderlider, Burton Smith, G. E. P. Smith, J. C. Stevens, R. K. Tiffany, 2097.
Report of the Committee of the Irrigation Division on Drainage of Irrigated Lands. Discussion: M. R. Lewis, 2203.
Report of the Duty of Water Committee of the Irrigation Division on the Consumptive Use of Water in Irrigation. Discussion: Harold Conkling, 2207.

Reservoirs
"Pumped-Storage Hydro-Electric Plants." William W. K. Freeman, 2457.
"Silting of the Lake at Austin, Texas." T. U. Taylor, 569. Discussion: L. M. Lawson, C. H. Eiffert, Oren Reed, 1345; Charles Schultz, John B. Hawley, 1649; H. F. Robinson, Julian Montgomery, Kirk Bryan, J. C. Stevens, 1939; P. A. Welty, Banks McLaurin, R. G. Tyler, E. C. H. Bantel, 2359; R. F. Walter, William Jenner Powell, R. I. Meeker, 2545.
"The O'Shaughnessy Dam and Reservoir." John H. Gregory, C. B. Hoover and C. B. Cornell, 405. Discussion: J. Ernest Carman, B. F. Jakobsen, 1325; W. H. Dittoe, G. Gale Dixon, 1635.
Transmission and delivery of reservoir water. 1080.

Rivers
"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John

P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"Flood Control with Special Reference to the Mississippi River": A Symposium. Discussion: J. P. Snow, Frank B. Maltby, Morris Knowles, Charles H. Paul, F. G. Jonah, 185; C. S. Jarvis, Edward H. Schulz, Q. C. Ayres, H. S. Gladfelter, Byron E. White, 881; W. G. Price, Oren Reed, Harold C. Fiske, Charles F. Brooks, William Gerig, C. H. Eiffert, Sherman M. Woodward, 1253; W. J. Schlick, 1565; S. L. Moyer, William M. Hall, C. E. Ramser, T. Kennard Thomson, 1843; W. E. Elam, R. W. Davenport, E. W. Lane, 2685.
"Hydraulic Studies and Operating Results on the Miami Flood Control System." C. H. Eiffert, 1371. Discussion: C. S. Bennett, Morris Knowles, Walter M. Smith, 2017; B. F. Jakobsen, 2415.
"Maximum Flood Discharge in San Joaquin Valley, California." Discussion: Robert Follansbee, Harold K. Fox, 651; Charles H. Lee, 1235; Oren Reed, 2107.
"Probability of Flood Flows." Discussion: Ralph R. Randell, 205; F. G. Switzer, 803.
Return water, North Platte River, Nebraska. 1098.
"The Delaware River from Philadelphia to the Sea." Discussion: Harry Taylor, F. C. Warner, 347; William Gerig, F. C. Boggs, 1537.
"The Effect of Agricultural Drainage Upon Flood Run-Off." Sherman M. Woodward and Floyd A. Nagler, 165.
"The O'Shaughnessy Dam and Reservoir." John H. Gregory, C. B. Hoover and C. B. Cornell, 405. Discussion: J. Ernest Carman, B. F. Jakobsen, 1325; W. H. Dittoe, G. Gale Dixon, 1635.
"Trans-Mountain Diversions." A Symposium. E. B. Debler, H. A. Van Norman, Robert Follansbee, 1109. Discussion: A. Lincoln Fellows, Ralph Bennett, 2195; B. F. Jakobsen, Paul M. Entenman, 2581.
"Water Supply Problems of a Desert Region." William E. Rudolph, 2287.

Roads
"Design and Construction of Concrete Pavements." Clifford Older, 147. Discussion: R. T. Giles, Elmer G. Hooper, 917; G. E. Hawthorn, H. O. Root, 1617; D. P. Krynine, 1913.
"Economic Comparisons of Various Types of Road Surfacing." A Symposium. F. E. Everett, H. J. Kuelling, 2477.
"Engineering Applied to National Parks." Stephen T. Mather, 2673.
"Foundations and Drainage of Highways." Albert C. Rose, 123. Discussion: Harry Tucker, Winslow H. Herschel, 913; Charles Terzaghi, D. P. Krynine, 1909.
"Relation of Road Type to Tire Wear." Discussion: O. L. Waller and H. E. Phelps, 583.

Run-Off
"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"Flood Control with Special Reference to the Mississippi River": A Symposium. Discussion: J. P. Snow, Frank B. Maltby, Morris Knowles, Charles H. Paul, F. G. Jonah, 185; C. S. Jarvis, Edward H. Schulz, Q. C. Ayres, H. S. Gladfelter, Byron E. White, 881; W. G. Price, Oren Reed, Harold C. Fiske, Charles F. Brooks, William Gerig, C. H. Eiffert, Sherman M. Woodward, 1253; W. J. Schlick, 1565; S. L. Moyer, William M. Hall, C. E. Ramser, T. Kennard Thomson, 1843; W. E. Elam, R. W. Davenport, E. W. Lane, 2685.
"Hydraulic Studies and Operating Results on the Miami Flood Control System." C. H. Eiffert, 1371. Discussion: C. S. Bennett, Morris Knowles, Walter M. Smith, 2017; B. F. Jakobsen, 2415.
"Maximum Flood Discharge in San Joaquin Valley, California." Discussion: Robert Follansbee, Harold K. Fox, 651; Charles H. Lee, 1235; Oren Reed, 2107.
"The Effect of Agricultural Drainage Upon Flood ——." Sherman M. Woodward and Floyd A. Nagler, 165.

Safety
"The Engineer's Part in Making the Highway Safe." A. H. Hinkle, 2089.

Sand
"The Compressibility of Sand-Mica Mixtures." Glennon Gilboy, 555. Discussion: R. D. N. Simham, William W. Rubey, 1933; Jacob Feld, 2357; D. P. Krynine, 2543.

Sanitation
"Historic Review of the Development of Sanitary Engineering in the United States During the Past One Hundred and Fifty Years": A Symposium. Discussion: George S. Webster, Morris Knowles, R. A. Hart, L. L. Hidinger, Roy N. Towl, 303; George H. Fenkell, N. T. Veatch, Jr., E. R. Jones, Leonard Greenburg, 605; Harry G. Payrow, George W. Fuller, Harrison P. Eddy, George Truman Palmer, 1171; James E. Brooks, W. G. Stromquist, S. H. McCrory, J. A. LePrince, 1501.

Septic Tanks
"Comments on the Design of Sludge Digestion Tanks." Richard H. Gould, 2655.

Sewage Disposal
"Comments on the Design of Sludge Digestion Tanks." Richard H. Gould, 2655.
"The —— Works of Decatur, Illinois." Samuel A. Greeley and William D. Hatfield, 2237.

Sewerage
"County Sewer District Work in Ohio and Assessment of Cost According to Benefits." E. G. Bradbury, 2061.
"The Sewage Disposal Works of Decatur, Illinois." Samuel A. Greeley and William D. Hatfield, 2237.

Shore Protection
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.

Signals
See Traffic Signals.

Silt
"Silting of the Lake at Austin, Texas." T. U. Taylor, 569. Discussion: L. M. Lawson, C. H. Eiffert, Oren Reed, 1345; Charles Schultz, John B. Hawley, 1649; H. F. Robinson, Julian Montgomery, Kirk Bryan, J. C. Stevens, 1939; P. A. Welty, Banks McLaurin, R. G. Tyler,

E. C. H. Bantel, 2359; R. F. Walter, William Jenner Powell, R. I. Meeker, 2545.
The —— problem of the Colorado River. 2583.

Siphons
"Stream Flow in General Terms." Melvin D. Casler, 97. Discussion: Frank S. Bailey, Cecil E. Pearce, 1605; F. Theodore Mavis, Morrough P. O'Brien, 1899.
"The Hydraulic Design of Flume and Siphon Transitions." Discussion: F. Theodore Mavis, W. H. R. Nimmo, Carl Rohwer, 1195.

Skew Arches
See Arches.

Slabs
"Design and Construction of Concrete Pavements." Clifford Older, 147. Discussion: R. T. Giles, Elmer G. Hooper, 917; G. E. Hawthorn, H. O. Root, 1617; D. P. Krynine, 1913.

Snow Removal
"—— Methods in New York, N. Y." Discussion: William Goldsmith, R. A. MacGregor, 353.

Soils
"Foundations and Drainage of Highways." Albert C. Rose, 123. Discussion: Harry Tucker, Winslow H. Herschel, 913; Charles Terzaghi, D. P. Krynine, 1909.
"Hydrostatic Uplift in Pervious ——." H. deB. Parsons, 941. Discussion: F. R. Harris, J. C. Meem, Eugene E. Halmos, T. R. Lawson, J. Vipond Davies, Lazarus White, T. Kennard Thomson, Daniel E. Moran, Alexander V. Gallogly, Allen Hazen, Charles Terzaghi, Frank S. Bailey, Charles R. Gow, E. L. Chandler, 1971; Martin J. McPike, Jacob Feld, 2377; J. Albert Holmes, E. W. Lane, 2707.
"The Compressibility of Sand-Mica Mixtures." Glennon Gilboy, 555. Discussion: R. D. N. Simham, William W. Rubey, 1933; Jacob Feld, 2357; D. P. Krynine, 2543.
"The Science of Foundations—Its Present and Future." Discussion: Charles R. Gow, E. P. Goodrich, Victor A. Endersby, 375; George Paaswell, C. C. Williams, Herbert Chatley, 655; J. Albert Holmes, Jacob Feld, 871; W. S. Housel, Frank S. Bailey, 1243; T. L. Condron, 1561; Lazarus White, R. D. N. Simham, Frank A. Marston, 1821; Arthur M. Shaw, 2313; D. P. Krynine, 2505.

Spillway
"Side Spillways for Regulating Diversion Canals." Discussion; Edward S. Lindley, 641; A. P. Flockart, George M. Bacon, 1527.
"The O'Shaughnessy Dam and Reservoir." John H. Gregory, C. B. Hoover and C B. Cornell, 405. Discussion: J. Ernest Carman, B. F. Jakobsen, 1325; W. H. Dittoe, G. Gale Dixon, 1635.

Strain
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.

Stream Flow
See Water, Flow of, in Open Channels.

Strength of Materials
"One Hundred Fifty Years Advance in Structural Analysis." H. M. Westergaard, 993. Discussion: S. Timoshenko, Alfred D. Flinn, Jacob Feld, 2383.

Stress
"A Graphic Method for Determining the Stresses in Circular Arches Under Normal Loads by the Cain Formulas." Discussion: William Cain, Walter L. Huber, Glen Edgar Edgerton, 333; Lars R. Jorgensen, 843; Fred A. Noetzli, 1531.
"A Proposed Formula for Columns." T. F. Hickerson, 1435. Discussion: William R. Osgood, 2401; Henry S. Prichard, E. H. Salmon, C. N. Ross, K. L. DeBlois, Edward Godfrey, 2721.
"Analysis of Arch Dams by the Trial Load Method." C. H. Howell and A. C. Jaquith, 61. Discussion: B. F. Jakobsen, George R. Rich, 1311; C. A. P. Turner, F. H. Constant, F. W. Hanna, 1585; L. J. Mensch, William Cain, 1879; J. L. Savage and Ivan E. Houk, Fred A. Noetzli, 2317; Fredrick Vogt, A. Floris, 2515.
"Crown Stresses in a Skew Arch." J. Charles Rathbun, 485. Discussion: B. F. Jakobsen, Edward Godfrey, 1639.
"Design and Construction of Concrete Pavements." Clifford Older, 147. Discussion: R. T. Giles, Elmer G. Hooper, 917; G. E. Hawthorn, H. O. Root, 1617; D. P. Krynine, 1913.
"Effect of Earth Shocks on Structures." M. de Bussey, 1449. Discussion: Rudolf Briske, Harry O. Wood, R. R. Martel, 2601.
"Load Distribution in High Arch Dams." R. A. Sutherland, 1027. Discussion: William Cain, B. F. Jakobsen, 2151; Paul Bauman, A. Floris, 2387.
"Notes on Arched Gravity Dams." Discussion: Paul Bauman, William Cain, F. W. Hanna, E. W. Kramer, A. J. Wiley, W. P. Creager, Edward Godfrey, C. A. P. Turner, 220; B. F. Jakobsen, 1479.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3. Discussion: Roy M. Green, Harry O. Wood, R. A. Sutherland, 2607.
"The Design of Tall Building Frames to Resist Wind." Albert W. Ross, Jr. and Clyde T. Morris, 1395. Discussion: David C. Coyle, Albert Smith, Robins Fleming, Everett C. Ebling, 2393.
"The Relation Between Earthquakes and Engineering Substructures." Henry D. Dewell, 1737. Discussion: Walter E. Spear, M. M. O'Shaughnessy, Bailey Willis, 2749.
"The Stiffness of Suspension Bridges." S. Timoshenko, 1464. Discussion: Lloyd G. Frost, Hans H. Rode, 2405; E. Steuermann and George C. Priester, 2737.

Subways
"Methods Used in the Construction of Twelve Pre-Cast Concrete Segments for the Alameda County, California, Estuary Subway." Discussion: Joseph A. Kitts, 1287.

Surveying
"Boundary Surveys." Discussion: William H. Richards, Jr., 355; R. H. Randall, W. H. Halsey, 647; Alexander Blair, Clarence T. Johnston, 1545.
"Horizontal Control in ——": Preliminary Report of the Committee of the —— and Mapping Division on Horizontal Control. George L. Hosmer, 2491.
"Specifications for Transit Traversing and Stadia Leveling." W. H. Rayner, 2639.
"Standard City Engineering Surveys." Robert H. Randall, 1749.

"—— and Mapping in the United States." Discussion. T. P. Pendleton, C. L. Hall, 339; John C. H. Lee, 845; C. H. Birdseye, 1535.
"Surveys on the Coast of New Jersey." Discussion: C. V. Hodgson, 345.

Tides
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.
"The Delaware River from Philadelphia to the Sea." Discussion: Harry Taylor, F. C. Warner, 347; William Gerig, F. C. Boggs, 1537.
"—— and Their Engineering Aspects." Discussion: F. W. Scheidenhelm, Charles H. Lee and Harold F. Gray, 209; G. T. Rude, 807.

Topography
"Surveying and Mapping in the United States." Discussion: T. P. Pendleton, C. L. Hall, 339; John C. H. Lee, 845; C. H. Birdseye, 1535.

Traffic
"Modernizing the Suburban Transit of the Metropolitan District." Francis Lee Stuart, 1391. Discussion: John A. Miller, Jr., Daniel L. Turner, Billings Wilson, Fred Lavis, Gustav Lindenthal, Charles Evan Fowler, 2587; Harold M. Lewis, 2711.
"Street Designing for Various Uses." George William Tillson, 1725. Discussion: Harold M. Lewis, W. W. Crosby, W. C. Sawyer, William C. Reeder, William T. Lyle, 2611.
"The Practical Utility of Highway Transport Surveys." G. F. Schlesinger, 2073. Discussion: R. H. Simpson, W. A. Van Duzer, C. R. Thomas, Jr., 2755.
"—— Control by Electric Signal Lights." Discussion: Lewis M. McIntyre, 1217; M. O. Eldridge, 1541.
"—— Control in New York, N. Y." Discussion: Russell S. Wise, C. D. Curtiss, E. P. Goodrich, 1221.

Traffic Signals
"Traffic Control by Electric Signal Lights." Discussion: Lewis M. McIntyre, 1217; M. O. Eldridge, 1541.
"Traffic Control in New York, N. Y." Discussion: Russell S. Wise, C. D. Curtiss, E. P. Goodrich, 1221.

Tramways
See Cableways.

Transportation
"Modernizing the Suburban Transit of the Metropolitan District." Francis Lee Stuart, 1391. Discussion: John A. Miller, Jr., Daniel L. Turner, Billings Wilson, Fred Lavis, Gustav Lindenthal, Charles Evan Fowler, 2587; Harold M. Lewis, 2711.
"The Isthmian Canal Situation." Hans Kramer, 1693.
"The Relation of Highway —— to the Railway." Discussion: Ralph Budd, 1153.

Triangulation
"Horizontal Control in Surveying": Preliminary Report of the Committee of the Surveying and Mapping Division on Horizontal Control. George L. Hosmer, 2491.

Trusses
"The Eye-Bar Cable Suspension Bridge at Florianopolis, Brazil." Discussion: Hardy Cross, 579; D. B. Steinman and William G. Grove, 1133.
"The Stiffness of Suspension Bridges." S. Timoshenko, 1464. Discussion: Lloyd G. Frost, Hans H. Rode, 2405; E. Steuermann and George C. Priester, 2737.

Tunnels
Inter-water-shed diversions by —— on United States Reclamation projects. 1110.

Valuation
"Evaluation of Water Rights." John E. Field, 1071. Discussion: Joseph Jacobs, Fred H. Tibbetts, Charles R. Hedke, Fred C. Scobey, Lyman E. Bishop, R. L. Parshall, 2157.
"Water-Power Appraisals." Discussion: Walter L. Huber, D. F. McCurrach, 325; Joel D. Justin, Dana M. Wood, Franklin H. Davis, 625; Le Roy K. Sherman, 837; J. H. Lance, William H. Cushman, 1521.

Waste Disposal
See Industrial Waste: Refuse Disposal: Sewage Disposal.

Water
"Administrative —— Problems." A Symposium. G. Clyde Baldwin, Edward Hyatt, George M. Bacon, 1079. Discussion: M. C. Hinderlider, R. I. Meeker, Lynn Crandall, E. B. Debler, 2177; Thomas R. Newell, 2577.
"Industrial Waste Disposal." A Symposium. Discussion: George W. Fuller, Almon L. Fales, 311; Edmund B. Besselievre, 615.
"The Treatment of the —— Supply of the City of Columbus, Ohio." Charles P. Hoover, 471. Discussion: F. H. Waring, George W. Fuller, Robert Spurr Weston, C. W. Foulk, 1329.

Water, Duty of
Report of the Duty of Water Committee of the Irrigation Division on the Consumptive Use of Water in Irrigation. Discussion: Harold Conkling, 2207.

Water, Flow of, in Open Channels
Administration of stream flow. 1085.
"Chemical-Electric Measurement of Water." A. Barbagelata, 789.
"Hydraulic Studies and Operating Results on the Miami Flood Control System." C. H. Eiffert, 1371. Discussion: C. S. Bennett, Morris Knowles, Walter M. Smith, 2017; B. F. Jakobsen, 2415.
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.
"Maximum Flood Discharge in San Joaquin Valley, California." Discussion: Robert Follansbee, Harold K. Fox, 651; Charles H. Lee, 1235; Oren Reed, 2107.
"Return Water and Drainage Recovery from Irrigation": A Symposium. R. H. Willis, D. W. Murphy, 1097. Discussion: R. I. Meeker, Fred H. Tibbetts, 2187.
"Stream Flow in General Terms." Melvin D. Casler, 97. Discussion: Frank S. Bailey, Cecil E. Pearce, 1605; F. Theodore Mavis, Morrough P. O'Brien, 1899.
"The Hydraulic Design of Flume and Siphon Transitions." Discussion: F. Theodore Mavis, W. H. R. Nimmo, Carl Rohwer, 1195.
"Water Supply Problems of a Desert Region." William E. Rudolph, 2287.

Water, Flow of, in Pipes
"Hydraulic Studies and Operating Results on the Miami Flood Control System."

C. H. Eiffert, 1371. Discussion: C. S. Bennett, Morris Knowles, Walter M. Smith, 2017; B. F. Jakobsen, 2415.
"Stream Flow in General Terms." Melvin D. Casler, 97. Discussion: Frank S. Bailey, Cecil E. Pearce, 1605; F. Theodore Mavis, Morrough P. O'Brien, 1899.
"The Hydraulic Design of Flume and Siphon Transitions." Discussion: F. Theodore Mavis, W. H. R. Nimmo, Carl Rohwer, 1195.

Water, Flow of, Over Dams and Weirs
"Baffle-Pier Experiments on Models of Pit River Dams." Discussion: Edward C. Sherman, 363; B. E. Torpen, Oren Reed, Harold K. Fox, 857; Robert F. Ewald, F. W. Scheidenhelm, 1225; Ralph L. Parshall, H. W. Dennis, I. A. Winter, 1549; Paul Bauman, Morrough P. O'Brien, 1807; J. C. Stevens, 2303.
"Precise Weir Measurements." Discussion: H. W. King, Floyd A. Nagler, 279; A. Streiff, 587; R. L. Parshall, 817; W. S. Pardoe, 1157; R. E. Ballester, Gardner S. Williams, 1493; Th. Rehbock, Erik G. W. Lindquist, 1767; Clemens Herschel, 2501.
"Stream Flow in General Terms." Melvin D. Casler, 97. Discussion: Frank S. Bailey, Cecil E. Pearce, 1605; F. Theodore Mavis, Morrough P. O'Brien, 1899.

Water, Flow of, Through Orifices
"Stream Flow in General Terms." Melvin D. Casler, 97. Discussion: Frank S. Bailey, Cecil E. Pearce, 1605; F. Theodore Mavis, Morrough P. O'Brien, 1899.

Water Power
"—— Appraisals." Discussion: Walter L. Huber, D. F. McCurrach, 325; Joel D. Justin, Dana M. Wood, Franklin, H. Davis, 625; Le Roy K. Sherman, 837; J. H. Lance, William H. Cushman, 1521.

Water Pressures
"Hydrostatic Uplift in Pervious Soils." H. de B. Parsons, 941. Discussion: F. R. Harris, J. C. Meem, Eugene E. Halmos, T. R. Lawson, J. Vipond Davies, Lazarus White, T. Kennard Thomson, Daniel E. Moran, Alexander V. Gallogly, Allen Hazen, Charles Terzaghi, Frank S. Bailey, Charles R. Gow, E. L. Chandler, 1971; Martin J. McPike, Jacob Feld, 2377; J. Albert Holmes, E. W. Lane, 2707.
"Upward Pressures Under Dams: Experiments by the United States Bureau of Reclamation." Julian Hinds, 685. Discussion: E. L. Chandler, 1349; B. F. Jakobsen, 1653; Charles Terzaghi, J. C. Stevens, F. W. Hanna, 1953; Ivan E. Houk, C. H. Howell, P. Wilhelm Werner, H. de B. Parsons, 2345.

Water Storage
"Pumped-Storage Hydro-Electric Plants." William W. K. Freeman, 2457.
"The O'Shaughnessy Dam and Reservoir." John H. Gregory, C. B. Hoover and C. B. Cornell, 405. Discussion: J. Ernest Carman, B. F. Jakobsen, 1325; W. H. Dittoe, G. Gale Dixon, 1635.

Waterways
"Advances in —— Engineering During a Half Century." Discussion: C. L. Hall, DeWitt D. Barlow, 643; W. M. Black, 2101.
"Flood Control on the River Po in Italy." John R. Freeman, 957. Discussion: C. McD. Townsend, Oren Reed, 1997; John P. Hogan, William B. Gregory, John R. Slattery, Arthur P. Davis, G. de Thierry, 2135; M. Giandotti, R. D. Goodrich, C. E. Grunsky, 2569.
"Flood Control with Special Reference to the Mississippi River": A Symposium. Discussion: J. P. Snow, Frank B. Maltby, Morris Knowles, Charles H. Paul, F. G. Jonah, 185; C. S. Jarvis, Edward H. Schulz, Q. C. Ayres, H. S. Gladfelter, Byron E. White, 881; W. G. Price, Oren Reed, Harold C. Fiske, Charles F. Brooks, William Gerig, C. H. Eiffert, Sherman M. Woodward, 1253; W. J. Schlick, 1565; S. L. Moyer, William M. Hall, C. E. Ramser, T. Kennard Thomson, 1843; W. E. Elam, R. W. Davenport, E. W. Lane, 2685.
"The Delaware River from Philadelphia to the Sea." Discussion: Harry Taylor, F. C. Warner, 347; William Gerig, F. C. Boggs, 1537.
"The Great Yangtze Bar." Discussion: A. W. Robinson, 327; R. L. Vaughn, 637.
"The Isthmian Canal Situation." Hans Kramer, 1693.

Water-Works
"The Treatment of the Water Supply of the City of Columbus, Ohio." Charles P. Hoover, 471. Discussion: F. H. Waring, George W. Fuller, Robert Spurr Weston, C. W. Foulk, 1329.
"Water Supply Problems of a Desert Region." William E. Rudolph, 2287.

Waves
"Inlets on Sandy Coasts." Earl I. Brown, 505. Discussion: G. T. Rude, 1339; W. M. Black, 1645; A. M. Strong, 1929; Morrough P. O'Brien, Elliott J. Dent, Augustus Smith, Victor Gelineau, 2329.

Weirs
See Water, Flow of, Over Dams and Weirs.

Wind
"The Design of Tall Building Frames to Resist ——." Albert W. Ross, Jr., and Clyde T. Morris, 1395. Discussion: David C. Coyle, Albert Smith, Robins Fleming, Everett E. Ebling, 2393.

World War
"Builders, Defenders, and Political Despoilers of Our Country": Address at the Annual Convention in Buffalo, N. Y., July 18, 1928. Lincoln Bush. 1683.

AUTHOR INDEX

Adams, Frederick Baird
Memoir of. 2040.

Adams, Henry Sewall
Memoir of. 2765.

Adams, Thomas
Regional community of the future. 1169.

Aisenstein, Michael D.
"Characteristics of Centrifugal Oil Pump." 1709.

Allison, James Ekin
Memoir of. 379.

Anderson, Walter S.
Qualifications of contractors. 2010.

Archibald, Warren Martin
Memoir of. 1671.

Armstrong, J. W.
Filtering material for sewage works. 2213.

Aylett, Philip
Memoir of. 1675.

Ayres, Q. C.
Mississippi River flood control. 902.

Bacon, George M.
"Present Tendencies in Water Administration." 1093.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.
Side spillways for diversion canals. 1528.

Bailey, Frank S.
Continuous beams over three spans. 1655.
Hydrostatic uplift in pervious soils. 1991.
Science of foundations. 1251.
Stream flow in general terms. 1605.

Bailey, Paul
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Bakenhus, R. E.
General versus segregated contracts. 1924.

Baker, Brookes
The planning of Longview, Wash. 815.

Baker, Donald M.
Basic information needed for regional plan. 597.

Balcom, H. G.
Final Report of the Committee of the Structural Division on Florida Hurricane. 1757.

Baldwin, G. Clyde
"Transmission and Delivery of Reservoir Water." 1080.

Ballard, Wilson T.
General versus segregated contracts. 1926.

Ballester, R. E.
Precise weir measurements. 1493.

Bantel, E. C. H.
Silting of lake at Austin, Texas. 2369.

Barbagelata, Angelo
"Chemical-Electric Measurement of Water." 789.

Barden, W. J.
Emergency dam on New Orleans Canal. 1275.
Lake Washington Ship Canal. 585.

Barlow, DeWitt D.
Progress in waterways engineering. 644.

Barnes, Thomas Howard
Memoir of. 931.

Barnett, Joseph
Cultural opportunities in regional planning. 824.

Barney, W. J.
General versus segregated contracts. 1626.

Barr, John Toner
Memoir of. 2621.

Bartholomew, Harland
"Base Maps for Regional Planning." 1745.
Basic information for regional plan. 289.

Bauman, Paul
Experiments on models of Pit River Dams. 1808.
Load distribution in high arch dams. 2387.
Notes on arched gravity dams. 219.

Bayly, Howard Paul
Memoir of. 2634.

Beahan, Willard
Memoir of. 2023.

Beanfield, R. McC.
Engineering features of a theatre building. 2124.

Beggs, George E.
"Test of a Celluloid Model of the Stevenson Creek Dam." May, Pt. 3, 219.

Beizner, Theodore
Engineering features of a theatre building. 1579.

Bennett, C. S.
Results of Miami flood control system. 2017.

Bennett, Ralph
Trans-mountain water diversions. 2196.

Besselievre, Edmund B.
Industrial waste disposal. 615.

Birdseye, C. H.
Surveying and mapping in the United States. 1535.

Bishop, Lyman E.
Evaluation of water rights. 2173.

Black, Roger D.
Emergency dam on New Orleans Canal. 1277.

Black, W. M.
Inlets on sandy coasts. 1645.
Progress in waterways engineering. 2101.

Blair, Alexander
Boundary surveys. 1545.

Blaisdell, A. H.
New theory for the centrifugal pump. 1189.

Blunt, William Titcomb
Memoir of. 2622.

Boggs, F. C.
Delaware River improvement. 1538.

Bowie, William
Flood protection data. 1666.

Boyden, H. C.
Qualifications of contractors. 2013.

Boynton, George Herbert
Memoir of. 2767.

Bradbury, E. G.
"County Sewer District Work in Ohio and Assessment of Cost According to Benefits." 2061.

Bremner, George Hampton
Memoir of. 2419.

Briske, Rudolph
Effect of earth shocks on structures. 2601.

Brooks, Charles F.
Mississippi River flood control. 1260.

Brooks, James E.
Development of sanitary engineering. 1501.

Brown, Earl I.
"Inlets on Sandy Coasts." 505.

Bryan, Kirk
Silting of lake at Austin, Texas. 1947.

Budd, Ralph
Highway transportation and the railway. 1153.
The Virginian Railway electrification. 1301.

Bush, Edward W.
General versus segregated contracts. 1319.
"Letting Construction Work by Competitive Bidding." 2437.

Bush, Lincoln
"Builders, Defenders, and Political Despoilers of our Country": Address at the Annual Convention in Buffalo, N. Y., July 18, 1928. 1683.

Cain, William
Arch dam analysis by trial load method. 1894.
Formulas for stresses in circular arches. 333.
Load distribution in high arch dams. 2151.
Notes on arched gravity dams. 228.

Carman, J. Ernest
The O'Shaughnessy Dam and Reservoir. 1325.

Carpenter, George Ansel
Memoir of. 1672.

Casler, Melvin D.
"Stream Flow in General Terms." 97.

Chandler, E. L.
Hydrostatic uplift in pervious soils. 1994.
Upward pressures under dams. 1349.

Chatley, Herbert
The science of foundations. 664.

Chester, J. N.
Filtering material for sewage works. 2216.

Child, Stephen
"Imagination in City Planning." 1009.

Christie, Ward P.
"General Contract System Versus Segregated Contracts." 395.

Clarke, Gilmore D.
Cultural opportunities in regional planning. 602.

Clifford, Walter Woodbridge
Memoir of. 2624.

Code, W. H.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Colnon, Redmond Stephen
Memoir of. 677.

Comer, R. O.
Emergency dam on New Orleans Canal. 1273.

Condron, T. L.
Effects of Florida hurricane. 2620.
The science of foundations. 1561.

Conkling, Harold
Consumptive use of water. 2207.

Constant, F. H.
Arch dam analysis by trial load method. 1593.

Cornell, C. B.
"The O'Shaughnessy Dam and Reservoir." 405.

Cox, A. B.
New theory for the centrifugal pump. 1801.

Coyle, David C.
Design of tall building frames to resist wind. 2393.
Final Report of the Committee of the Structural Division on Florida Hurricane. 1757.

Crandall, Lynn
Administrative water problems. 2182.

Crane, Clarence Austin
Memoir of. 2025.

Creager, W. P.
Notes on arched gravity dams. 259.

Crosby, W. W.
Imagination in city planning. 2147.
Street designing for various uses. 2613.

Cross, Hardy
Florianopolis Bridge. 579.

Curry, Charles Kenneth
Memoir of. 2776.

Curtiss, C. D.
Traffic control in New York, N. Y. 1222.

Cushman, William H.
Water-power appraisals. 1523.

Davenport, R. W.
Mississippi River flood control. 2695.

Davies, J. Vipond
Hydrostatic uplift in pervious soils. 1980.

Davis, Arthur P.
Flood control on the River Po. 2140.

Davis, Franklin H.
Water-power appraisals. 633.

Davis, Raymond E.
"Physical Properties of Concrete." May, Pt. 3, 199.

Dawley, William Sanborn
Memoir of. 2770.

Debler, E. B.
Administrative water problems. 2185.
"Inter-Water-Shed Diversions by Tunnels, U. S. Reclamation Projects." 1110.

DeBlois, K. L.
Proposed formula for columns. 2730.

de Bussy, M.
"Effect of Earth Shocks on Structures." 1449.

Dennis, H. W.
Experiments on models of Pit River Dams. 1554.
"Financing and Constructing the Experimental Arch Dam." May, Pt. 3, 43.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Dent, Elliott J.
Inlets on sandy coasts. 2330.

Derleth, C., Jr.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

de Thierry, G.
Flood control on the River Po. 2143.

Dewell, Henry D.
"The Relation Between Earthquakes and Engineering Substructures." 1737.

Dittoe, W. H.
The O'Shaughnessy Dam and Reservoir. 1635.

Dixon, G. Gale
The O'Shaughnessy Dam and Reservoir. 1635.

Donnell, Lloyd H.
New theory for the centrifugal pump. 1514.

Dougherty, H. M.
General versus segregated contracts. 1631.

Dufour, F. O.
Effects of Florida hurricane. 2619.

Eastham, Robert Francis
Memoir of. 933.

Ebling, Everett E.
Design of tall building frames to resist wind. 2398.

Eddy, Harrison P.
Development of sanitary engineering. 1175.
Flood protection data. 1661.

Edgerton, Glen Edgar
Formulas for stresses in circular arches. 336.

Edwards, Guy Banker
Memoir of. 2427.

Elffert, C. H.
"Hydraulic Studies and Operating Results on the Miami Flood Control System." 1371.
Mississippi River flood control. 1266.
Silting of lake at Austin, Texas. 1346.

Elam, W. E.
Mississippi River flood control. 2685.

Eldridge, M. O.
Traffic control by electric signal lights. 1541.

Eliot, Charles W., 2d.
Cultural opportunities in regional planning. 601.

Elliott, J. A.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Emerson, George Dana
Memoir of. 380.

Endersby, Victor A.
The science of foundations. 377.

Entenman, Paul M.
Trans-mountain water diversions. 2582.

Ericson, John Ernst
Memoir of. 1359.

Everett, F. E.
"Economic Comparisons of Road Surfaces—New Hampshire." 2478.

Ewald, Robert F.
Experiments on models of Pit River Dams. 1225.

Fales, Almon L.
Industrial waste disposal. 312.

Feld, Jacob
Advance in structural analysis. 2385.
Compressibility of sand-mica mixtures. 2357.
Hydrostatic uplift in pervious soils. 2381.
The science of foundations. 876.

Fellows, A. Lincoln
Trans-mountain water diversions. 2195.

Felt, Charles Frederick Wilson
Memoir of. 2626.

Fenkell, George H.
Development of sanitary engineering. 605.

Field, John E.
"Evaluation of Water Rights." 1071.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Fiske, Harold C.
Mississippi River flood control. 1257.

Flagg, Josiah Foster
Memoir of. 2219.

Fleming, Robins
Design of tall building frames to resist wind. 2395.

Fletcher, Austin Bradstreet
Memoir of. 2220.

Flinn, Alfred D.
Advance in structural analysis. 2384.
"Earthquakes, Ice, and Deterioration of Concrete." May, Pt. 3, 267.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Flockart, A. P.
Side spillways for diversion canals. 1527.

Floris, A.
Analysis of arch dams by trial load method. 2532.
Engineering features of a theatre building. 2119.
Load distribution in high arch dams. 2391.

Follansbee, Robert
Flood discharge in San Joaquin Valley, Calif. 651.
"Trans-Mountain Diversions in Colorado." 1123.

Foulk, C. W.
Water supply purification, Columbus, Ohio. 1336.

Fowler, Charles Evan
Metropolitan district suburban transit. 2598.

Fox, Harold K.
Experiments on models of Pit River Dams. 868.
Flood discharge in San Joaquin Valley, Calif. 652.

Freeman, John R.
"Flood Control on the River Po in Italy." 957.
Flood protection data. 1667.

Freeman, William W. K.
"Pumped-Storage Hydro-Electric Plants." 2457.

Frost, Lloyd G.
The stiffness of suspension bridges. 2405.

Fuller, George W.
Development of sanitary engineering. 1172.
Industrial waste disposal. 311.
Water supply purification, Columbus, Ohio. 1333.

Gallogly, Alexander V.
Hydrostatic uplift in pervious soils. 1983.

Gelineau, Victor
Inlets on sandy coasts. 2338.

Gerig, William
Delaware River improvement. 1537.
Mississippi River flood control. 1265.

Giandotti, M.
Flood control on the River Po. 2569.

Gibbs, George
"The Virginian Railway Electrification." 3. Discussion. 2701.
Giesting, Frank Alexander
Memoir of. 2231.
Gilboy, Glennon
"The Compressibility of Sand-Mica Mixtures." 555.
Giles, R. T.
Design and construction of concrete pavements. 917.
Gladfelter, H. S.
Mississippi River flood control. 903.
Godfrey, Edward
Crown stresses in a skew arch. 1640.
Notes on arched gravity dams. 260.
Proposed formula for columns. 2733.
Goethals, George Washington
Memoir of. 2223.
Going, Alvah Seymour
Memoir of. 2421.
Goldsmith, William
Snow removal methods in New York, N. Y. 353.
Goodell, John Milton
Memoir of. 391.
Goodrich, E. P.
The science of foundations. 377.
Traffic control in New York, N. Y. 1222.
Goodrich, R. D.
Flood control on the River Po. 2571.
Gould, Richard H.
"Comments on the Design of Sludge Digestion Tanks." 2655.
Gow, Charles R.
Hydrostatic uplift in pervious soils. 1972.
The science of foundations. 375.
Gray, Harold F.
Tides and their engineering aspects. 211.
Greeley, Samuel A.
"The Sewage Disposal Works of Decatur, Illinois." 2237.
Green, Hubert Edward
Memoir of. 678.
Green, Roy M.
Arch dam investigation. 2607.
Greenburg, Leonard
Development of sanitary engineering. 612.
Gregory, John H.
"The O'Shaughnessy Dam and Reservoir." 405.
Gregory, William B.
Flood control on the River Po. 2136.
Grove, William G.
Florianopolis Bridge. 1133.
Gruenberger, O.
New theory for the centrifugal pump. 324.
Grunsky, C. E.
Flood control on the River Po. 2575.
Flood protection data. 1662.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.
Hadley, H. M.
Continuous beams over three spans. 2559.
Hageman, H. A.
Conowingo hydro-electric development. 667.
Hall, C. L.
Progress in waterways engineering. 643.
Surveying and mapping in the United States. 342.
Hall, William M.
Mississippi River flood control. 1855.
Halmos, Eugene E.
Hydrostatic uplift in pervious soils. 1978.
Halsey, W. H.
Boundary surveys. 648.
Hammatt, Edward Augustus White
Memoir of. 382.
Hammond, A. J.
Flood protection data. 1665.
Hanna, F. W.
Arch dam analysis by trial load method. 1598.
Notes on arched gravity dams. 232.
Upward pressures under dams. 1958.
Hare, S. Herbert
The planning of Longview, Wash. 816.
Harris, Elmo G.
New theory for the centrifugal pump. 318.
Harris, F. R.
Emergency dam on New Orleans Canal. 673.
Hydrostatic uplift in pervious soils. 1971.
Hart, R. A.
Development of sanitary engineering. 307.
Hatfield, William D.
"The Sewage Disposal Works of Decatur, Illinois." 2237.
Hatton, T. Chalkley
Qualifications of contractors. 2014.
Hawgood, H.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.
Hawley, John B.
Silting of lake at Austin, Texas. 1650.
Hawthorn, G. E.
Construction of concrete pavements. 1617.
Haydock, Winters
Cultural opportunities in regional planning. 601.
Hazen, Allen
Hydrostatic uplift in pervious soils. 1984.
Hedke, Charles R.
Evaluation of water rights. 2169.
Henny, D. C.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.
Some phases of irrigation financing. 267.
Herschel, Clemens
Precise weir measurements. 2501.
Herschel, Winslow H.
Foundations and drainage of highways. 914.
Heyworth, James Ormerod
Memoir of. 2422.
Hickerson, T. F.
"A Proposed Formula for Columns." 1435.
Hidinger, L. L.
Development of sanitary engineering. 307.
Hill, E. R.
The Virginian Railway electrification. 1304.
Hill, R. A.
Concrete dam construction. 827.

Hinderlider, M. C.
Administrative water problems. 2177.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Hinds, Julian
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.
"Upward Pressures Under Dams: Experiments by the United States Bureau of Reclamation." 685.

Hinkle, A. H.
"The Engineer's Part in Making the Highway Safe." 2089.

Hodgson, C. V.
Surveys on the New Jersey Coast. 345.

Hogan, John P.
Flood control on the River Po. 2135.
The Virginian Railway electrification. 1581.

Hogg, T. H.
Re-design of Catawba Station. 372.

Holmes, J. Albert
Hydrostatic uplift in pervious soils. 2707.
The science of foundations. 871.

Hooper, Elmer G.
Design and construction of concrete pavements. 919.
New theory for the centrifugal pump. 621.

Hoover, C. B.
"The O'Shaughnessy Dam and Reservoir." 405.

Hoover, Charles P.
"The Treatment of the Water Supply of the City of Columbus, Ohio." 471.

Hosmer, George L.
"Horizontal Control in Surveying." Preliminary Report of the Surveying and Mapping Division on Horizontal Control. 2491.

Hosmer, Guy Frederic
Memoir of. 1364.

Houk, Ivan E.
Arch dam analysis by trial load method. 2317.
"Tests on Models at Boulder, Colorado." May, Pt. 3, 215.
Upward pressures under dams. 2345.

Housel, W. S.
The science of foundations. 1243.

Howell, C. H.
"Analysis of Arch Dams by the Trial Load Method." 61.
Upward pressures under dams. 2351.

Hubbard, Frank James
Memoir of. 2628.

Huber, Walter L.
Formulas for stresses in circular arches. 336.
Water-power appraisals. 325.

Hyatt, Edward
"Administration of Stream Flow." 1085.

Hyde, A. Lincoln
Continuous beams over three spans. 1962.

Ihlder, John
Cultural opportunities in regional planning. 824.
Housing and the regional plan. 821.

Jacobs, Joseph
Evaluation of water rights. 2157.

Jakobsen, B. F.
Arch dam analysis by trial load method. 1311.
Crown stresses in a skew arch. 1639.
General versus segregated contracts. 1322.
Load distribution in high arch dams. 2153.
Notes on arched gravity dams. 1479.
Results of Miami flood control system. 2415.
The O'Shaughnessy Dam and Reservoir. 1327.
Trans-mountain water diversions. 2581.
Upward pressures under dams. 1653.

Japlot, Marcel
The Virginian Railway electrification. 1296.

Jaquith, A. C.
"Analysis of Arch Dams by the Trial Load Method." 61.

Jarvis, C. S.
Mississippi River flood control. 881.

Jenks, Harry N.
Filtering material for sewage works. 2214.

Johnston, Clarence T.
Boundary surveys. 1546.

Jonah, F. G.
Mississippi River flood control. 200.

Jones, E. R.
Development of sanitary engineering. 611.

Jones, Fred Atwood
Memoir of. 2773.

Jorgensen, Lars R.
Formulas for stresses in circular arches. 843.

Joslin, H. V.
Re-design of Catawba Station. 371.

Junkersfeld, P.
The civil engineer and power development. 923.

Justin, Joel D.
The civil engineer and power development. 928.
Water-power appraisals. 625.

Kennedy, James Henry
Memoir of. 2026.

King, H. W.
Precise weir measurements. 279.

Kitts, Joseph A.
Methods on pre-casting concrete segments. 1287.

Klyce, Battle Hargrove
Memoir of. 2774.

Knowles, Morris
Development of sanitary engineering. 305.
Mississippi River flood control. 190.
Qualifications of contractors. 2011.
Results of Miami flood control system. 2020.
The regional community of the future. 291.

Kramer, E. W.
Notes on arched gravity dams. 242.

Kramer, Hans
"The Isthmian Canal Situation." 1693.

Krynine, D. P.
Compressibility of sand-mica mixtures. 2543.
Construction of concrete pavements. 1913.
Foundations and drainage of highways. 1912.
The science of foundations. 2505.

Kuelling, H. J.
"Economic Comparisons of Road Surfaces—Wisconsin." 2482.

Lally, John Michael
Memoir of. 680.

Lance, J. H.
Water-power appraisals. 1521.

Lane, E. W.
Hydrostatic uplift in pervious soils. 2708.
Mississippi River flood control. 2697.

Lavis, Fred
Metropolitan district suburban transit. 2595.

Lawson, L. M.
Silting of lake at Austin, Texas. 1345.

Lawson, T. R.
Hydrostatic uplift in pervious soils. 1979.

Leavitt, Charles Wellford
Memoir of. 2228.

Leckliter, Walter Harlan
Memoir of. 2233.

Lee, Charles H.
Flood discharge in San Joaquin Valley. 1235.
Tides and their engineering aspects. 211.

Lee, John C. H.
Surveying and mapping in the United States. 845.

Le Prince, J. A.
Development of sanitary engineering. 1506.

Levy, Alfred
Memoir of. 2635.

Lewis, Harold M.
Basic information needed for regional plan. 1165.
Metropolitan district suburban transit. 2711.
Street designing for various uses. 2611.

Lewis, M. R.
Drainage of irrigated lands. 2203.

Liddicoat, R. T.
New theory for the centrifugal pump. 1511.

Lindenthal, Gustav
Metropolitan district suburban transit. 2597.

Lindley, Edward S.
Head-works of the Imperial Canal. 2103.
Side spillways for diversion canals. 641.

Lindquist, Erik G. W.
Precise weir measurements. 1786.

Lippincott, J. B.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Litchfield, Norman
The Virginian Railway electrification. 1305.

Lyle, William T.
General versus segregated contracts. 1321.
Street designing for various uses. 2617.

MacGregor, R. A.
Snow removal methods in New York, N. Y. 354.

McConnell, I. W.
"The Role of the Civil Engineer in Power Development." 155.

McCrory, S. H.
Development of sanitary engineering. 1505.

McCurrach, D. F.
Water-power appraisals. 326.

McIntyre, Lewis W.
Traffic control by electric signals. 1217.

McLaurin, Banks
Silting of lake at Austin, Texas. 2364.

McMillan, F. R.
Final Report of the Committee of the Structural Division on Florida Hurricane. 1757.

McMinn, Thomas James
Memoir of. 1360.

McPike, Martin J.
Hydrostatic uplift in pervious soils. 2377.

Maitland, Alexander, Jr.
Memoir of. 383.

Maltby, Frank B.
Mississippi River flood control. 187.

March, Harry J.
Basic information needed for regional plan. 599.
Cultural opportunities in regional planning. 603.

Marston, Frank A.
The science of foundations. 1838.

Martel, R. R.
Effect of earth shocks on structures. 2603.

Marvin, Frank Olin
Memoir of. 385.

Marx, Charles D.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Mather, Stephen T.
"Engineering Applied to National Parks." 2673.

Matthes, Gerard H.
Flood protection data. 1657.

Mavis, F. Theodore
Design of flume and siphon transitions. 1195.
New theory for the centrifugal pump. 831.
Stream flow in general terms. 1899.

Maxson, Frank Oscar
Memoir of. 2029.

Meals, Casper D.
Aerial tramways. 849.

Medici, Mario
New theory for the centrifugal pump. 1177.

Meeker, R. I.
Administrative water problems. 2181.
Return water from irrigation. 2187.
Silting of lake at Austin, Texas. 2556.

Meem, J. C.
Hydrostatic uplift in pervious soils. 1972.

Mensch, L. J.
Arch dam analysis by trial load method. 1879.

Meredith, Wynne
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Midolo, Mario John
Memoir of. 2041.

Miller, John A., Jr.
Metropolitan district suburban transit. 2587.

Miller, Lee H.
Final Report of the Committee of the Structural Division on Florida Hurricane. 1757.

Monniche, T. B.
Emergency dam on New Orleans Canal. 1569.

Montgomery, Julian
Silting of lake at Austin, Texas. 1946.

Moran, Daniel E.
Hydrostatic uplift in pervious soils. 1982.

Morgan, Arthur E.
Flood protection data. 1663.

Morris, Clyde T.
Continuous beams over three spans. 1961.
Final Report of the Committee of the Structural Division on Florida Hurricane. 1757.
"The Design of Tall Building Frames to Resist Wind." 1395.

Moyer, S. L.
Mississippi River flood control. 1843.

Mueller, Chester
"Concrete Pavement Over Poor Sub-Grade at Port Newark, New Jersey." 2045.

Muhs, C. C.
General versus segregated contracts. 1623.

Munk, Max M.
New theory for the centrifugal pump. 317.

Murphy, D. W.
"Drainage Recovery from Irrigation." 1103.

Nagle, James C.
Memoir of. 2230.

Nagler, Floyd A.
Precise weir measurements. 283.
"The Effect of Agricultural Drainage Upon Flood Run-Off." 165.

Nauman, George
Memoir of. 2630.

Newell, Joseph S.
"The Design of Airplane Wing-Beams." 725.

Newell, Thomas R.
Administrative water problems. 2577.

Niles, Alfred S.
Design of airplane wing-beams. 2127.

Nimmo, W. H. R.
Design of flume and siphon transitions. 1204.

Noetzli, Fred A.
Arch dam analysis by trial load method. 2325.
"Arch Dams: An Experimental Investigation." May, Pt. 3, 11.
Concrete dam construction. 1509.
Engineering features of a theatre building. 1580.
Formulas for stresses in circular arches. 1531.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

O'Brien, Morrough P.
Experiments on models of Pit River Dams. 1817.
Inlets on sandy coasts. 2329.
New theory for the centrifugal pump. 1192.
Stream flow in general terms. 1902.

Oesterblom, I.
"Continuous Beams Over Three Spans." 709.

Ofverholm, I.
The Virginian Railway electrification. 1300.

Older, Clifford
"Design and Construction of Concrete Pavements." 147.

Onstott, Virgil Samms
Memoir of. 2428.

O'Reilly, John Devereux
Memoir of. 934.

Orrok, George A.
The civil engineer and power development. 925.

Osgood, William R.
Proposed formula for columns. 2401.

O'Shaughnessy, M. M.
Earthquakes and engineering substructures. 2751.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May. Pt. 3.

Paaswell, George
Aerial tramways. 847.
The science of foundations. 655.

Palmer, George Truman
Development of sanitary engineering. 1176.

Pardoe, W. S.
Precise weir measurements. 1157.

Parshall, Ralph L.
Evaluation of water rights. 2175.
Experiments on models of Pit River Dams. 1549.
Precise weir measurements. 817.

Parsons, H. de B.
"Hydrostatic Uplift in Pervious Soils." 941.
Upward pressures under dams. 2354.

Paul, Charles H.
Mississippi River flood control. 199.

Payrow, Harry G.
Development of sanitary engineering. 1171.

Pearce, Cecil E.
Stream flow in general terms. 1606.

Pendleton, T. P.
Surveying and mapping in the United States. 339.

Perkins, Frank William
Memoir of. 388.

Phelps, H. E.
Relation of road type to tire wear. 583.

Pohl, Charles A.
Flood-protection data. 2199.

Porter, H. Hobart
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Potter, W. B.
The Virginian Railway electrification. 1295.

Powell, William Jenner
Silting of lake at Austin, Texas. 2553.

Price, W. G.
Mississippi River flood control. 1253.

Prichard, Henry S.
Proposed formula for columns. 2721.

Priester, George C.
Stiffness of suspension bridges. 2741.

Proctor, Ralph F.
Qualifications of contractors. 2005.

Ramser, C. E.
Mississippi River flood control. 1869.

Randall, R. H.
Boundary surveys. 647.
"Standard City Engineering Surveys." 1749.

Randell, Ralph R.
Probability of flood flows. 205.

Rathbun, J. Charles
"Crown Stresses in a Skew-Arch." 485.

Ray, George J.
The Virginian Railway electrification. 1309.

Rayner, R. H.
"Specifications for Transit Traversing and Stadia Leveling." 2639.

Reed, Oren
Experiments on models of Pit River Dams. 867.
Flood control on the River Po. 2002.
Flood discharge in San Joaquin Valley. 2107.
Mississippi River flood control. 1256.
Silting of lake at Austin, Texas. 1347.

Reeder, William C.
Street designing for various uses. 2616.

Rehbock, Th.
Precise weir measurements. 1767.

Rich, George R.
Arch dam analysis by trial load method. 1315.

Richards, William H., Jr.
Boundary surveys. 355.

Ridgway, Robert
General versus segregated contracts. 1922.

Riggs, Morris John
Memoir of. 2031.

Robinson, A. W.
The great Yangtze Bar. 327.

Robinson, H. F.
Silting of lake at Austin, Texas. 1939.

Rode, Hans H.
The stiffness of suspension bridges. 2406.

Rohwer, Carl
Design of flume and siphon transitions. 1209.

Root, H. O.
Construction of concrete pavements. 1620.

Rose, Albert C.
"Foundations and Drainage of Highways." 123.

Rose, John Gansovertte
Memoir of. 2429.

Rose, Rudolf Viedt
Memoir of. 2424.

Rosecrans, Merle William
Memoir of. 935.

Ross, Albert W., Jr.
"The Design of Tall Building Frames to Resist Wind." 1395.

Ross, C. N.
Proposed formula for columns. 2727.

Rubey, William W.
Compressibility of sand-mica mixtures. 1936.

Rude, G. T.
Inlets on sandy coasts. 1339.
Tides and their engineering aspects. 807.

Rudolph, William E.
"Water Supply Problems of a Desert Region." 2287.

Sabin, L. C.
Lake Washington Ship Canal. 273.

Salmon, E. H.
Proposed formula for columns. 2726.

Sargent, A. W.
Lake Washington Ship Canal. 585.

Sargent, J. A.
The civil engineer and power development. 1917.

Savage, John L.
Arch dam analysis by trial load method. 2317.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.
"Test on Models at Boulder, Colorado." May, Pt. 3, 215.

Sawyer, W. C.
Street designing for various uses. 2614.

Scheidenhelm, F. W.
Experiments on models of Pit River Dams. 1231.
The civil engineer and power development. 929.
Tides and their engineering aspects. 209.

Schlesinger, G. F.
"The Practical Utility of Highway Transport Surveys." 2073.

Schlick, W. J.
Mississippi River flood control. 1565.

Schultz, Charles
Silting of lake at Austin, Texas. 1649.

Schulz, Edward H.
Mississippi River flood control. 894.

Scobey, Fred C.
Evaluation of water rights. 2173.

Scofield, Glenn Mason
Memoir of. 2033.

Semenza, Guido
The Virginian Railway electrification. 1302.

Shaw, Arthur M.
The science of foundations. 2313.

Sheets, Frank T.
"Qualifications of Contractors on Public Works." 1021.

Shepard, F. H.
The Virginian Railway electrification. 1303.

Sheridan, Howard Augustus
Memoir of. 681.

Sherman, Edward C.
Experiments on models of Pit River Dams. 363.

Sherman, Le Roy K.
Water-power appraisals. 837.

Shurtleff, Arthur A.
Imagination in city planning. 2148.
"Relation of the Landscape Architect to the Allied Professions Engaged in City Planning." 2667.

Silicox, L. K.
The Virginian Railway electrification. 1298.

Simham, R. D. N.
Compressibility of sand-mica mixtures. 1933.
Imagination in city planning. 2409.
The science of foundations. 1834.
The Virginian Railway electrification. 1875.

Simpson, R. H.
Highway transport surveys. 2755.

Slater, Willis A.
"Report of Tests on Stevenson Creek Dam." May, Pt. 3, 49.

Slattery, John R.
Flood control on the River Po. 2137.

Sleight, Reuben Benjamin
Memoir of. 1365.

Smith, Alfred
Design of tall building frames to resist wind. 2394.

Smith, Augustus
Inlets on sandy coasts. 2334.

Smith, Burton
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Smith, G. E. P.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.

Smith, Walter M.
Results of Miami flood control system. 2021.

Snow, J. P.
Mississippi River flood control. 185.

Snyder, Hunter Imboden
Memoir of. 1677.

Spear, Walter E.
Earthquakes and engineering substructures. 2749.

Spencer, John Clark
Memoir of. 389.

Spooner, Allen Newhall
Memoir of. 936.

Starrett, W. A.
General versus segregated contracts. 1921.

Steinman, D. B.
Florianopolis Bridge. 1133.

Steuermann, E.
Stiffness of suspension bridges. 2737.

Stevens, J. C.
Experiments on models of Pit River Dams. 2303.
Report of the Committee of the Irrigation Division on a National Reclamation Policy. 2097.
Silting of lake at Austin, Texas. 1950.
Upward pressures under dams. 1957.

Stewart, Lucern S.
Memoir of. 2777.

Stiles, L. S.
General versus segregated contracts. 1629.

Strachan, Robert C.
Aerial tramways. 359.

Streiff, A.
Precise weir measurements. 587.

Strickland, Kirby Lee
Memoir of. 2034.

Stromquist, W. G.
Development of sanitary engineering. 1503.

Strong, A. M.
Inlets on sandy coasts. 1929.

Stuart, Francis Lee
"Modernizing the Suburban Transit of the Metropolitan District." 1391.

Sutherland, R. A.
Arch dam investigation. 2609.
"Load Distribution in High Arch Dams." 1027.

Switzer, F. G.
Flood protection data. 1660.
Probability of flood flows. 803.

Talbot, Arthur N.
Flood protection data. 1664.

Tallman, Paul Bertram
Memoir of. 2425.

Tate, Robert L'Hommedieu
Memoir of. 1674.

Taylor, Harry
Delaware River improvement. 347.

Taylor, T. U.
"Silting of the Lake at Austin, Texas." 569.

Terzaghi, Charles
Foundations and drainage of highways. 1909.
Hydrostatic uplift in pervious soils. 1985.
Upward pressures under dams. 1953.

Thomas, C. R., Jr.
Highway transport surveys. 2762.

Thomson, T. Kennard
General versus segregated contracts. 1631.
Hydrostatic uplift in pervious soils. 1981.
Mississippi River flood control. 1870.

Thorndike, Sturgis Hooper
Memoir of. 2631.

Tibbetts, Fred H.
Evaluation of water rights. 2164.
Return water from irrigation. 2190.

Tiffany, R. K.
Report of the Committee of the Irrigation Division on A National Reclamation Policy. 2097.
State reclamation in Washington. 581.

Tillman, Frank Andrew
Memoir of. 2432.

Tillson, George William
"Street Designing for Various Uses." 1725.

Timoshenko, S.
Advance in structural analysis. 2383.
New theory for the centrifugal pump. 1515.
"The Stiffnes of Suspension Bridges." 1464.

Torpen, B. E.
Experiments on models of Pit River Dams. 857.

Towl, Roy N.
Development of sanitary engineering. 309.

Townsend, C. McD.
Flood control on the River Po. 1997.

Tripp, Oscar Holmes
Memoir of. 679.

Tucker, Harry
Foundations and drainage of highways. 913.

Turner, C. A. P.
Arch dam analysis by trial load method. 1585.
Notes on arched gravity dams. 261.

Turner, Daniel L.
Metropolitan district suburban transit. 2591.

Tuska, Gustave R.
General versus segregated contracts. 1630.

Tyler, R. G.
Silting of lake at Austin, Texas. 2367.

Van Duzer, W. A.
Highway transport surveys. 2759.

Van Norman, H. A.
"The Proposed Los Angeles-Colorado River Aqueduct." 1116.

Vaughn, R. L.
The great Yangtze Bar. 637.

Veatch, N. T., Jr.
Development of sanitary engineering. 609.

Vogt, Fredrik
Arch dam analysis by trial load method. 2515.

Wagner, Frank
Memoir of. 1678.

Waller, Laurence J.
Engineering features of a theatre building. 2123.

Waller, O. L.
Relation of road type to tire wear. 583.

Walter, R. F.
Silting of lake at Austin, Texas. 2545.

Waring, F. H.
Water supply purification, Columbus, Ohio. 1329.

Warner, Edwin Hall
Memoir of. 2036.

Warner, Frank C.
Delaware River improvement. 349.

Way, W. F.
Continuous beams over three spans. 2373.

Webster, George S.
Development of sanitary engineering. 303.

Weir, M. W.
Imagination in city planning. 2412.

Wells, William Bacon
Memoir of. 2779.

Welty, P. A.
Silting of lake at Austin, Texas. 2359.

Werner, P. Wilhelm
Upward pressures under dams. 2353.

Wessman, Harold E.
Continuous beams over three spans. 1964.

Westergaard, H. M.
"One Hundred Fifty Years' Advance in Structural Engineering." 993.
"Theoretical Analysis of the Structural Action of the Stevenson Creek Arch Dam." May, Pt. 3, 231.

Weston, Robert Spurr
Water supply purification, Columbus, Ohio. 1335.

Weymouth, F. E.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Wheeler, Bertrand Thorp
Memoir of. 2038.

Wheeler, Levi Lockwood
Memoir of. 1362.

White, Byron E.
Mississippi River flood control. 905.

White, Lazarus
General versus segregated contracts. 1628.
Hydrostatic uplift in pervious soils. 1981.
The science of foundations. 1821.

Whitehead, R. H.
Emergency dam on New Orleans Canal. 675.

Wilder, Robert M.
Continuous beams over three spans. 1969.

Wiley, A. J.
Notes on arched gravity dams. 254.

Williams, C. C.
The science of foundations. 657.

Williams, Gardner S.
Precise weir measurements. 1499.

Willis, Bailey
Earthquakes and engineering substructures. 2752.

Willis, R. H.
"Return Water, North Platte River, Nebraska." 1098.

Wilson, Billings
Metropolitan district suburban transit. 2593.

Winter, I. A.
Experiments on models of Pit River Dams. 1558.

Wise, Russell S.
Traffic control in New York, N. Y. 1221.

Withington, Sidney
The Virginian Railway electrification. 1307.

Wood, Dana M.
Water-power appraisals. 627.

Wood, Harry O.
Arch dam investigation. 2609.
Effect of earth shocks on structures. 2603.

Woodard, Silas H.
Report of Committee of Engineering Foundation on Arch Dam Investigation. May, Pt. 3.

Woodward, Sherman M.
Mississippi River flood control. 1270.
"The Effect of Agricultural Drainage Upon Flood Run-Off." 165.

Young, Samuel McC.
Emergency dam on New Orleans Canal. 1285.

DEC 3 1928

PROCEEDINGS

of the

American Society

of

Civil Engineers

TWO PARTS

PART 1

DECEMBER, 1928

CONTENTS

SPECIFICATIONS FOR TRANSIT TRAVERSING AND STADIA LEVELING
By W. H. RAYNER, ASSOC. M. AM. SOC. C. E.

COMMENTS ON THE DESIGN OF SLUDGE DIGESTION TANKS
By RICHARD H. GOULD, M. AM. SOC. C. E.

RELATION OF THE LANDSCAPE ARCHITECT TO THE ALLIED PROFESSIONS ENGAGED IN ENGINEERING
By ARTHUR A. SHURTLEFF, ESQ.

ENGINEERING APPLIED TO NATIONAL PARKS
By STEPHEN T. MATHER, ESQ.

ANNUAL MEETING, NEW YORK, N. Y.
JANUARY 16-18, 1929

CURRENT PAPERS AND DISCUSSIONS

		Discussion closes
Flood Control with Special Reference to the Mississippi River: A Symposium	Dec., 1927	Jan., 1928
Discussion	Jan., Mar., April, May, Aug., Dec., 1928	Closed
"The Virginian Railway Electrification." GEORGE GIBBS	Jan., 1928	
Discussion (Author's closure)	April, May, Aug., Dec., 1928	Closed
"Hydrostatic Uplift in Pervious Soils." H. DE B. PARSONS	April, 1928	
Discussion	April, May, Aug., Dec., 1928	Dec., 1928
"Flood Control on the River Po in Italy." JOHN R. FREEMAN	April, 1928	
Discussion	Aug., Sept., Nov., 1928	Dec., 1928
"One Hundred and Fifty Years Advance in Structural Engineering." H. M. WESTERGAARD	April, 1928	
Discussion	Oct., 1928	Dec., 1928
"Imagination in City Planning." STEPHEN CHILD	April, 1928	
Discussion	Sept., Oct., 1928	Dec., 1928
"Load Distribution in High Arch Dams." R. A. SUTHERLAND	April, 1928	
Discussion	Sept., Oct., 1928	Dec., 1928
"Evaluation of Water Rights." JOHN E. FIELDS	April, 1928	
Discussion	Sept., 1928	Dec., 1928
Administrative Water Problems: A Symposium	April, 1928	
Discussion	Sept., Nov., 1928	Dec., 1928
Return Water and Drainage Recovery from Irrigation: A Symposium	April, 1928	
Discussion	Sept., 1928	Dec., 1928
Trans-Mountain Water Diversions: A Symposium	April, 1928	
Discussion	Sept., Nov., 1928	Dec., 1928
Report of Duty of Water Committee of the Irrigation Division on the Consumptive Use of Water	April, 1928	
Discussion	Sept., 1928	Uncertain
"Hydraulic Studies and Operating Results on the Miami Flood Control System." C. H. EIFFERT	May, 1928	
Discussion	Aug., Oct., 1928	Dec., 1928
"Modernizing the Suburban Transit of the Metropolitan District." FRANCIS LEE STUART	May, 1928	
Discussion	Nov., Dec., 1928	Uncertain
"The Design of Tall Building Frames to Resist Wind." ALBERT W. ROSS, JR., and CLYDE T. MORRIS	May, 1928	
Discussion	Oct., 1928	Dec., 1928
"A Proposed Formula for Columns." T. F. HICKERSON	May, 1928	
Discussion	Oct., Dec., 1928	Dec., 1928
"Effect of Earth Shocks on Structures." M. DE BUSSY	May, 1928	
Discussion	Nov., 1928	Dec., 1928
"The Stiffness of Suspension Bridges." S. TIMOSHENKO	May, 1928	
Discussion	Oct., Dec., 1928	Dec., 1928
Report of the Committee of Engineering Foundation on Arch Dam Investigation.	May, 1928	
Discussion	Nov., 1928	Uncertain
"The Isthmian Canal Situation." HANS KRAMER	Aug., 1928	Dec., 1928
"Characteristics of Centrifugal Oil Pump." M. D. AISENSTEIN	Aug., 1928	Dec., 1928
"Street Designing for Various Uses." G. W. TILLSON	Aug., 1928	
Discussion	Nov., 1928	Dec., 1928
"The Relation Between Earthquakes and Engineering Substructures." HENRY D. DEWELL	Aug., 1928	
Discussion	Dec., 1928	Jan., 1929
"Base Maps for Diagonal Planning." HARLAND BARTHOLOMEW	Aug., 1928	Jan., 1929
"Standard City Engineering Surveys." ROBERT H. RANDALL	Aug., 1928	Jan., 1929
Final Report of Committee of Structural Division on Florida Hurricane	Aug., 1928	
Discussion	Nov., 1928	Jan., 1929
"Concrete Pavement Over Poor Sub-Grade at Port Newark, New Jersey." CHESTER MUELLER	Sept., 1928	Jan., 1929
"County Sewer District Work in Ohio and Assessment of Cost According to Benefits." E. G. BRADBURY	Sept., 1928	Jan., 1929
"The Practical Utility of Highway Transport Surveys." G. F. SCHLESINGER	Sept., 1928	
Discussion	Dec., 1928	Jan., 1929
"The Engineer's Part in Making the Highway Safe." A. H. HINKLE	Sept., 1928	Jan., 1929
Report of the Committee of the Irrigation Division on A National Reclamation Policy	Sept., 1928	Uncertain
"The Sewage Disposal Works of Decatur, Illinois." SAMUEL A. GREELEY and WILLIAM D. HATFIELD	Oct., 1928	Feb., 1929
"Water Supply Problems of a Desert Region." WILLIAM E. RUDOLPH	Oct., 1928	Feb., 1929
"Letting Construction Work by Competitive Bidding." EDWARD W. BUSH	Nov., 1928	Feb., 1929
"Pumped-Storage Hydro-Electric Plants." WILLIAM W. K. FREEMAN	Nov., 1928	Mar., 1929
Economic Comparisons of Various Types of Road Surfaces: A Symposium	Nov., 1928	Mar., 1929
Horizontal Control in Surveying: Preliminary Report of the Committee of the Surveying and Mapping Division on Horizontal Control. GEORGE L. HOSMER	Nov., 1928	Mar., 1929

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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January 14-15, 1929:

A Quarterly Meeting will be held at New York, N. Y.

ANNUAL MEETING, NEW YORK, N. Y.
January 16, 17, and 18, 1929

January 16, 1929:

Morning.—Annual Meeting, Conferring of Honorary Membership, and Presentation of Prizes and Medals.

Afternoon.—Presentation and Discussion of Division and Special Committee Reports.

Evening.—President's Reception and Dinner Dance.

January 17, 1929:

Morning.—Technical Division Meetings.

Afternoon.—Technical Division Meetings.

Evening.—Entertainment and Smoker.

January 18, 1929:

All-Day Excursion.

SPRING MEETING, DALLAS, TEXAS,
April 24, 25, and 26, 1929

The Reading Room of the Society is open from 9 A. M. to 6 P. M. every day, except Sundays, New Year's Day, Washington's Birthday, Memorial Day, Fourth of July, Labor Day, Thanksgiving Day, and Christmas Day; during July and August it is closed at 5 P. M., except on Saturdays when it closes at 12 M.

Members, particularly those from out of town, are cordially invited to use this room on their visits to New York, to have their mail addressed there, and to utilize it as a place for meeting others. There is a file of 276 current periodicals, the latest technical books, and the room is well supplied with writing tables.